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94-RF-11268

November 8, 1994

Norma I. Castaneda
Environmental Restoration Division
DOE/RFFO

SUBMITTAL OF THE DRAFT REPORT ON POTASSIUM FERRATE PRECIPITATION TREATABILITY STUDY - WSB-129-94

Action: Review and comment on draft report.

Enclosed please find two copies of the draft report on the Potassium Ferrate Precipitation Treatability Study for your review and comment. This report covers the first and second phases of the bench-scale study. ACTA Resources, Inc., the subcontractor performing the treatability study, will then incorporate reviewers' comments into the final version of the report. The final document will also include Phase 3 analytical results, which have yet to be received.

As you know, the Environmental Protection Agency and the Colorado Department of Public Health and Environment have directed the Department of Energy / Rocky Flats Field Office (DOE/RFFO) and EG&G Rocky Flats, Inc. to provide them with treatability study results from the Sitewide Treatability Studies Program no later than November 12, 1994. This draft report may be used to fulfill that requirement.

Should you have any questions or comments, please contact W. J. Roushey of the Treatability Studies/Feasibility Studies Team at extension 6951 or page 1711.

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3 PARTIAL/OPEN
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POTASSIUM FERRATE
TREATMENT OF RFP GROUNDWATER

DRAFT 1

NOVEMBER 5, 1994

DOCUMENT CONTROL NUMBER

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1.0 INTRODUCTION

The potassium ferrate treatment study of Rocky Flats (RFP) ground water was performed under the Sitewide Treatability Studies Program (STSP). This study was undertaken to determine the effectiveness of potassium ferrate in a conventional water treatment system to remove the contaminants of concern from ground water at the Rocky Flats Environmental Technologies Site (RFETS). Potassium ferrate is a simple salt where the iron is in the plus six valence state. It is the iron at the plus six valence state (Fe^{+6}) that makes it an unique water treatment chemical, especially in waters where the pH is greater than seven. In basic solutions the solubility of the oxides/hydroxides of many contaminants of concern is low. As solids they can be effectively

~~removed by conventional water treatment systems.~~ Contaminated groundwater for this study was collected from monitoring wells, 3086, 09091, B206789, and 7287 and combined to yield a single water sample for this study.

The objective of this study was to determine the quality of water after treatment with potassium ferrate and to determine if the Colorado Water Quality Control Commission (CWQCC) discharge limits for the contaminants of concern listed in Table 1.0-1 could be met. The radionuclides in the groundwater were of special interest.

Laboratory work was performed by personnel from the Environmental Technologies and Environmental Engineering Technology group of Rocky Flats Plant under the supervision and direction of ACTA Resources, Inc. All potassium ferrate study test work was performed in Laboratory 264, Building 881 in accordance with the guide lines of the treatability work plan "Work Plan for Potassium Ferrate Treatment of RFP Ground Water, July 1994".

Table 1.0-1 CWQCC Discharge Limits

Analytes	Discharge Limits
Radionuclides, pCi/l	
Gross alpha (a)	7-11
Gross beta (b)	5-19
Am 241	0.05
Pu 239,240	0.05
U total	5-10
Target Metals, mg/l	
Aluminum	0.087
Antimony	0.024
Barium	1.0
Beryllium	0.004
Cadmium	0.0015
Chromium	0.05
Cobalt	0.05
Iron	0.3
Lead	0.028
Manganese	0.56
Mercury	0.00001
Nickel	0.125
Selenium	0.01
Silver	0.00059
Vanadium	0.1
Zinc	0.35

Analysis of the untreated and treated water samples generated during this study were done by Accu-Labs Research, Inc. using EPA methods listed in Table 1.0-2 following the required QA / QC procedures.

Table 1.0-2 Analytical Methods and Detection Limits Used in This Study

Analytes	Analytical Method	Detection Limit	Units
Radionuclides			
Gross alpha/beta	EPA 900.0	3-4	pCi/l
Am 241	ALR 3804224	0.01	pCi/l
Pu 238,239,240	ALR 3804223	0.01	pCi/l
U, total	EPA 908.1	0.005	mg/l
Target Metals			
Aluminum	EPA 200.7	0.05	mg/l
Antimony	EPA 204.7	0.005	mg/l
Barium	EPA 200.7	0.05	mg/l
Beryllium	NA	N.A.	mg/l
Cadmium	EPA 213.2	0.0005	mg/l
Chromium	EPA 200.7	0.005	mg/l
Cobalt	EPA 200.7	0.005	mg/l
Iron	EPA 200.7	0.01	mg/l
Lead	EPA 239.2	0.005	mg/l
Manganese	EPA 200.7	0.005	mg/l
Mercury	best available method	0.0001	mg/l
Nickel	EPA 200.7	0.01	mg/l
Selenium	EPA 270.2	0.005	mg/l
Silver	EPA 272.2	0.0002	mg/l
Vanadium	NA	N.A.	mg/l
Zinc	EPA 200.7	0.005	mg/l

Design of the test matrix and the analysis of the resulting data was done using a computer program called ECHIP (ECHIP, Inc. 724 Yorklyn Road, Hockessin, DE 19707-8703). This statistical based program was used for several reasons. First, the examination and interpretation of the large number of measured responses, 16 elements and 3 radionuclides, required a model program for test protocol optimization. Second, the low concentration of the contaminants of concern created significant error associated with the analysis and it was desired to minimize the impact of this when the data was evaluated. Third, there were four primary variables in the first phase of the study and it was desired to examine their individual and collective interactive effect on each of the responses.

In the past various treatment techniques have been used to cleanup the RFP ground water, but none have been successful in removing all the contaminants to below the CWQCC discharge limits. For example, filtration with a 0.45 micron membrane removed most contaminants to below the Applicable or Relevant and Appropriate Requirements (ARARs) but failed to eliminate uranium and selenium (Roushey, October 1993; Laul and Muller, July 1994). However, one prior test (Evaluation of TRU/Clear, a potassium based water treatment chemical, Fernald Purchase Order Number 317505-00, February 8, 1991) showed that the uranium concentration in waste water could be reduced by 90 to 99+ percent using potassium ferrate. A second study conducted on C-2 Pond Water (Rocky Flats Contract # ASC77254BW) again showed that the uranium could be reduced to less than 0.2 percent of the original concentration. Because of its ability to remove uranium from waters, it is very likely that potassium ferrate would also be effective in removing other known contaminants in the RFP groundwater. These contaminants should precipitate and be removed from solution leaving a water that meets the CWQCC discharge limits.

1.1 SITE DESCRIPTION

1.1.1 Site Name and Description

RFETS, a 6550 acre industrial reservation, is located in northern Jefferson County, Colorado. The RFETS is situated on a recent Alluvium which overlays the Arapahoe sandstone formation, the two major geological stratigraphic units. The Alluvium consists of weathered claystone (Kac1) and the Arapahoe formation (Kass), being the bedrock in the area, consists of weathered and unweathered sandstone. Based on a hydrogeological survey the Alluvium is more permeable to groundwater than the Arapahoe unit (U.S. DOE 1991, 1992).

Monitoring wells within the RFP reservation are all drilled through the Alluvian and penetrated the Arapahoe formation 10 to 20 feet. The contaminated waters used in this study were drawn from these monitoring wells using EPA sampling techniques.

1.1.2 History of Operations

From the mid-1950s to the present, RFETS has been a government-owned [Department of Energy (DOE)] contractor-operated facility which manufactured weapon components primarily from plutonium, uranium, beryllium and stainless steels. RFETS also reprocessed certain plutonium residues for the recovery of weapons grade plutonium. Metals reprocessing, using a variety of chemicals and solvents, generated wastes which were discharged to holding facilities.

From the 1960s to the 1970s five Solar Evaporation Ponds (SEPs) were constructed (i.e. 207A, 207B North, 207 Center, 207 South, and 207 c). These ponds received and stored liquid wastes

from various buildings on the RFETS. The operation of the RFETS caused some inadvertent contamination of the ground water on the site through a path yet to be determined.

1.2 GROUND WATER DESCRIPTION

Water for this study, which had been collected prior to the start of the program, came from four monitoring wells on the RFETS. These wells were 3086, 09091, B206789, and 7287. The water had been archived in one gallon polyethylene bottles which were enclosed in plastic bags. To make a sufficiently large sample for the entire three phases of the study multiple gallon samples from each well were used and mixed in a 30 gallon polyethylene tank. The approximate volumes from each well are shown in Table 1.2-1.

Table 1.2-1 Approximate Volume of Ground Water from various Monitoring Wells

Monitoring Well	Approximate Volume Used
Number	Gallons
3086-	4.00
09091	7.00
B206789	2.00
7287-	6.50

The composite sample was analyzed during each phase of the study to make sure there were no changes in the contaminant concentration due to such factors as the formation of organic growth in the storage container. Analysis of the three samples for each phase of the study with the average concentrations and statistical data are given in Table Number 1.2-2.

Table 1.2-2 Analysis of Untreated Water at Beginning of Each Phase of the Study

Element	Units	1st Phase	2nd Phase	3rd Phase	Average	S.D.
Silver	mg/l	0.029	0.028			
Aluminum	mg/l	18.0	20.0			
Barium	mg/l	0.23	0.23			
Beryllium	mg/l	<0.005	<0.005			
Cadmium	mg/l	<0.005	<0.005			
Cobalt	mg/l	0.007	0.006			
Chromium	mg/l	0.020	0.025			
Copper	mg/l	0.029	0.023			
Iron	mg/l	19.0	19.0			
Manganese	mg/l	0.24	0.24			
Molybdenum	mg/l	<0.01	<0.01			
Nickel	mg/l	0.02	<0.05			
Antimony	mg/l	<0.05	<0.05			
Selenium	mg/l	0.044	0.040			
Thallium	mg/l	<0.1	<0.5			
Vanadium	mg/l	0.042	0.043			
Zinc	mg/l	0.086	0.081			
Arsenic	mg/l	0.016	0.010			
Mercury	mg/l	<0.0001	<0.0001			
Lead	mg/l	0.012	0.013			
Radionuclides						
Am 241	pCi/l	0.86 +/-0.36				
Pu 239/240	pCi/l	7.5 +/-0.93				
Uranium	mg/l	0.044				

1.3 TREATMENT TECHNOLOGY DESCRIPTION

Removal of metallic or other contaminants from water by normal water treatment techniques requires that the contaminants form a solid phase of sufficient particle size so that they settle out of the water. To accomplish this in water treatment systems, reagents are added to the water and/or the pH is adjusted to precipitate the contaminants. Various treatment chemicals can be added to assist the agglomeration process to achieve the desired removal results. Additional treatment chemicals can be added to enhance the solids concentration of the solution. These aid the sweep floc formation and precipitation of the suspended solids from solution. In any water treatment process, it is necessary to have some minimum solid content present in the solution for simple settling to effectively remove contaminants. In some processes filtration can be used in place of settling or to polish the water but it tends to be a more expensive unit operation. Therefore, filtration was not part of this study.

Because of its unique chemistry potassium ferrate has been studied for its use in water treatment by many investigators. The iron in potassium ferrate is in the plus 6 valence state. Iron based chemicals used in water treatment for many years are normally in the plus two or plus three valence state. It appears, that this difference in valence state is the reason that ferrate produces different results than normal iron treatment chemicals used in water treatment. Ferrate appears to be more effective in collecting and coagulating fine solids in water, especially radionuclides. Several reasons for this enhanced removal have been suggested. First, the ferrate slowly decomposes in basic solutions, allowing greater interaction between the suspended solid. This phenomena is different when compared to the almost immediate formation of iron(III) hydroxide when iron(III) sulfate is added to basic solution. Second, the decomposition of the potassium ferrate produces an iron oxide / hydroxide that seem to attach to other solids in the water more effectively than the ferric hydroxide produced with other iron water treating chemicals. Third,

there is the potential for the formation of insoluble heavy metal ferrate compounds that are also removed from solution by settling. This enhanced removal efficiency of iron(VI) is also experienced when comparing ferrate to other customarily used water treatment chemicals. Whatever the actual mechanism, it is believed that by using potassium ferrate, in addition to other water treatment chemicals, it would be possible to clean the RFP groundwater to concentrations lower than conventional treatment methods. Implementation of this simple chemical treatment process should meet the CWQCC water discharge limits for the contaminants present.

The water treatment process to be used in the study is similar to a conventional water treatment process except that two steps are added. The two additional steps are the introduction and degradation process of the potassium ferrate chemical. The general process steps and the desired effect are as follows:

1. Adjust pH: This initial step is needed to produce insoluble metal hydroxides (solids) which will be removed from the water in the subsequent steps. It needs to be mentioned here that as the pH of the contaminant solution rises, most of the metals become more insoluble.

2. Add potassium ferrate: This step requires time to allow ferrate to proceed through several decomposition steps which coagulate the metal hydroxide solids to form large particles. Decomposition of ferrate enhances the agglomeration of the suspended fine hydroxide particles to these larger particles and promotes efficient solids removal during the solids settling process.

3. Reduce the remaining ferrate: Ferrate decomposes at a slow rate in those solutions with a high pH (> 10.0), therefore, it is necessary to eliminate the excess with a chemical reducing agent. This is necessary because any ferrate remaining in the solution may prevent the

removal of some of the contaminants. In this study, the reductant used was sodium thiosulfate. The reaction product in this case will be potassium sulfate, an unregulated water impurity.

4. Add alum: Alum (aluminum sulfate) when added to the wastewater forms aluminum hydroxide floc which is very voluminous. This voluminous floc formed from the addition of a small amount of alum disperses and fills space throughout the reaction vessel. This greatly increases the chance that all of the suspended particles will be bridged with the aluminum hydroxide thereby creating larger particles.

5. Add an organic polymer: Since aluminum hydroxide is light and it does not settle well, an organic polymer is used to make the flocculants heavier so they settle faster.

During the entire laboratory test the pH is controlled at the desired value with either potassium hydroxide or sulfuric acid. In plant operations, pH adjustment will occur prior to the treatment process with the treated effluent monitored before discharge. The addition of caustic at the beginning of the process will be controlled.

1.4 Previous Studies of Ferrate Water Treatment at RFP

One previous study of potassium ferrate has been conducted on the RFP site. This study "Evaluation of the TRU/Clear™ Chemical Process System (Phase I and Phase II was issued August 1990, Contract Number ASC 77254BW). In this study surrogates of radionuclide contaminants were added to water to simulate the wastewater produced when the plutonium processing plant was in full operation. Treatment of these waste with TRU/Clear™ decreased the gross alpha radioactivity from 3.0×10^6 to 6000 pCi/l or a reduction of 99.8 percent. This was below the desired water radioactivity goal of 12,500 pCi/l for these studies. In addition the

weight of solids produced was six to seven times lower than that produced using the reagent iron(III) sulfate. This study using TRU/Clear™ as an additive demonstrated that the plant would meet the established discharge limits and do so with a significant reduction of the amount of radioactive sludge produced.

2.0 CONCLUSIONS AND RECOMMENDATIONS

(To Be Written After Receipt Of Phase III Results)

3.0 TREATABILITY STUDY APPROACH

3.1 Test Objectives and Rationale

It has been claimed by some investigators that using ferrate in conjunction with a conventional treatment process will yield superior removal of inorganic metals and radionuclides from wastewater and at the same time produce less solid waste to be disposed. Conventional water treatment plants are relatively easy to design, build and operate and the operational costs are relatively low when compared to other treatment methods. The use of ferrate appeared to be an appropriate technology to apply to the RFP ground water problem. As with all technologies a simple preliminary feasibility study of the process was needed to determine if the goals of the desired cleanup standards could be met. In view of the federal and state water discharge restrictions for the Rocky Flats Site and the ferrate treatment efficiency claims made, the study "Potassium Ferrate Treatment of RFP Ground Water" was approved and undertaken.

The overall goal of this study was to determine if ferrate technology could remove the contaminants of concern from ground water on the site to a level that would allow the treated water to be discharged into surface waters. More specifically the goal was to meet the CWQCC discharge limits given in Table 1.0-1 with emphasis on the radionuclides.

To determine the contaminant removal efficiency of using potassium ferrate in a conventional water treatment process, a multiphase program was used. At the suggestion of a representative of the Colorado Department of Health, a statistical design modeling program was used to setup and evaluate the results of this study with specific objectives established for the individual phases of the program. A computer program (ECHIP) which is a statistically based experimental design package was utilized for the design of the test matrix for each phase of this study. Use of this

program enabled the investigators to more clearly elucidate the reasons for the success or lack of success of the study undertaken. The specific objectives of the three phases are as follows:

Phase I objectives: to determine the relative effect of the following variables on each of the contaminants of concern for:

- a) potassium ferrate concentration
- b) pH of the water during treatment
- c) the need for and the effects of alum addition
- d) the need for and the effects of organic polymer addition.

Phase II objectives: to use the information obtained in Phase I and establish process conditions that:

- a) minimize reagent consumption
- b) maintains acceptable removal of the contaminants.

Phase III objectives: to use the information gathered in the previous two phases of testing to:

- a) confirm the efficiency of the process
- b) gather preliminary engineering data.

3.2 EXPERIMENTAL DESIGN AND PROCEDURES

3.2.1 Experimental Design

Design of the experiments for this study was controlled by a computer program that is based on a large body of literature of statistical experiment design. This program ECHIP is licensed to ACTA from ECHIP Inc., 724 Yorklyn Road, Hockessin, DE 19707-8703. Discussion in detail of the program basis and function is not appropriate for this report, but some discussion is needed to understand the reasoning for this particular experimental design.

In the first phase of the study it was desired to study four variables: the effect of ferrate; the effect of pH; the need for alum; and the need for organic polymer. To do this, a linear screening test design was used. This test design estimates the first order effects of the variables plus the constant in the linear equation only. There is some danger in using this design in that interactive effect of the variables may not be found. This is because it was necessary to limit the number of tests required to collect sufficient data for mathematical analysis. The equation established by the program was:

$$y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4$$

In this equation y is the measured response which is the analytical concentration in solution. There are four calculated constants (a_0 , a_1 , a_2 , a_3 and a_4). The unknowns are: x_1 - the equilibrium pH, x_2 - the amount of ferrate in mg/l, x_3 - the amount of alum in mg/l, and x_4 - the amount of polymer in mg/l. The computer utilizing all the test results, calculated the constants and compared the calculated equation with the actual values and determined the degree of fit. The computer program also has the ability to create two and three dimensional plots of the each of the

responses measured. In this study, 19 responses were measured. The test matrix used for the first phase is given in Table 3.2-1. Tests were run in the order presented in Table 3.2-1 to eliminate any systematic errors that might occur during testing.

Table 3.2-1 Test matrix used for the First Phase of this Study

Test Number	pH	Ferrate (mg/L)	Alum (mg/L)	Polymer (mg/L)
11-	10.000	47.150	30.000	2.750
3-	11.500	15.700	50.000	5.000
8-	8.500	15.700	50.000	5.000
4-	8.000	78.600	10.000	0.500
2-	11.500	15.700	10.000	0.500
5-	11.500	78.600	10.000	5.000
7-	11.500	78.600	50.000	0.500
6-	8.500	15.700	50.000	0.500
3-	11.500	15.700	50.000	5.000
10-	8.500	15.700	10.000	0.500
2-	11.500	15.700	10.000	0.500
1-	8.500	78.600	50.000	5.000
9-	11.500	78.600	50.000	5.000
1-	8.500	78.600	50.000	5.000

Design of the tests for Phase II depended upon the results obtained in Phase I. If any of the variables showed little or no response they would be eliminated from further consideration. For the second phase a design was used that estimates any interaction effects if they existed.

Interaction effects are important to measure in that it might be possible to use more of a cheaper reagent and less of an expensive reagent and still achieve the same results. In other words, an economic optimum can be found. The model to be used in the second phase, if any variables are eliminated from the search, would be one of the three interactive models available in the ECHIP program. The selection of the model was based upon the best fit of the data. If all four variables were retained the number of tests in Phase II would have been excessive. However, Phase I indicated that the amount of alum and organic polymer did not have any major effects so their dosage levels were fixed for the second phase. The only variables investigated during Phase II testing were ferrate addition and pH.

The amount of alum and polymer used in all of the second phase tests were set at 20 mg/l and 10 mg/l, respectively. The test matrix developed for Phase II is given in Table 3.2-2.

To eliminate systematic testing errors the tests were run in the order they are given in Table 3.2-2.

Phase III consists of several tests to 1) confirm the results obtained in Phase II, and 2) gather some preliminary engineering data. Since these were confirmation and system design tests, an ECHIP programmed test design was not necessary.

Table 3.2-2 Phase II Test Matrix

Test Number	pH	log(mg/l ferrate)	mg/l ferrate added (conversion shown for convenience only)
3-	7.800	2.200	158.500
4-	8.810	1.570	37.200
3-	7.800	2.200	158.500
12-	9.650	2.200	158.500
11-	9.630	1.089	12.300
9-	11.500	0.000	1.000
1-	11.500	2.200	158.500
2-	11.500	1.100	12.600
8-	9.650	2.200	158.500
1-	11.500	2.200	158.500
10-	10.450	0.602	4.000
1-	11.500	2.200	158.500
2-	11.500	1.100	12.600
2-	11.500	1.100	12.600

3.3 Experimental Equipment, Materials, and Procedures

3.3.1 Experimental Equipment

In addition to the usual standard laboratory glassware and plastic bottles, a Phipps and Bird stirring unit with two liter B-KER²™ beakers was used. This stirrer is the standard unit for conducting water treatment experiments. It allows for good control of the energy input to the stirrer to aid in scale-up. The pH meter used was an Orion 230 which was calibrated every time a measurement was made.

3.3.2 Experimental Materials

Except for two chemicals all were purchased from a chemical supply house and were analytical grade or better. The two exceptions were the organic polymer and the potassium ferrate. The organic polymer is a product of Cytec (a division of American Cyanamid Co.) called Magnifloc 985N, a nonionic polyacrylamide. Potassium ferrate used was 45% pure with the balance of the product being a mixture of potassium chloride and potassium hydroxide with minor amount of magnesium salts. This product was produced by Analytical Development Co. (Colorado Springs, Colorado).

The reagents used in the test and their concentrations as added are:

KOH (potassium hydroxide)	50% solution
Na ₂ S ₂ O ₃ (sodium thiosulfate)	5% solution
K ₂ FeO ₄ (potassium ferrate)	dry powder (45%)
Alum (aluminum sulfate, Al ₂ SO ₄)	40 mg/l solution
Polymer (Cytec 984 N, made fresh daily)	2 mg/l solution

3.3.3 Experimental Procedures

Groundwater from several monitoring wells was mixed in a 30 gallon tank in the laboratory several days in advance of the beginning of testing. See Tables 1.2-1 and 1.2-2 for the source and composition of the water sample used in these tests. The laboratory was at a constant temperature so the water sample had thermally equilibrated. The tank was covered with a plastic membrane to minimize evaporation, then covered with the hard tank cover.

Prior to taking water from this tank it was thoroughly mixed for several minutes until the settled solids were all suspended. Two liter samples for each test were taken by dipping into the tank with a plastic beaker, measured in a 1000 ml graduated cylinder, and transferred to the test apparatus.

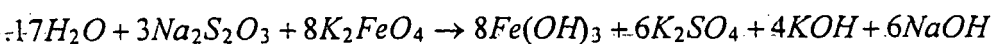
Usually four test were run at a time since the Phipps and Bird Stirrer had four stirrer positions. The beakers (B-Ker™) were filled with two liters of the ground water to be treated. The B-Ker™ polycarbamate beakers are 4.5 inches by 4.5 inches square and approximately eight inches deep. The stirrer blade is three inches by one inch by one quarter inch and its speed is controlled to within 2% of the test rpm.

The test solutions were stirred at 300 rpm. The pH was measured and adjusted to the desired test condition, using potassium hydroxide in all cases. During the pH adjustment, the electrode was immersed in the water for constant measurement as the solution was being stirred.

When the pH had been adjusted to the appropriate level, the dry potassium ferrate was added. The dry ferrate was weighed on an electronic balance located in the testing laboratory and has an accuracy of 0.0001 gram. The entire amount of the ferrate was added to the solution. This

solution was stirred for a set time in Phase I (15 minutes). During Phase II the time of mixing was varied depending on the amount of ferrate added. (Variations in mixing times are discussed in section 4.2.)

In a basic solution potassium ferrate is relatively stable, therefore a small amount of sodium thiosulfate, a reducing agent, was added during the mixing stage to cause the ferrate to decompose. In Phase I the amount of sodium thiosulfate added was based on the following stoichiometric equation:



This equation gave the stoichiometric requirements of:

$$\text{mg sodium thiosulfate} = 0.3 (\text{mg potassium ferrate}).$$

This equation was used to calculate the amount of thiosulfate required to completely reduce the ferrate. The equation may not accurately represent the actual products of the reaction. This is of no consequence since the thiosulfate / ferrate molar ratio is not affected. For example, if the iron product is assumed to be either $FeO(OH)$ or Fe_2O_3 , the relationship between thiosulfate and ferrate is the same.

In Phase II the amount of sodium thiosulfate used was that amount required to eliminate the purple color of the ferrate. The actual amount used was recorded and becomes a variable to be examined with the other test results.

In Phase I the thiosulfate solution was added quickly while mixing was continued at 300 rpm and continued for 15 minutes. During the tests in Phase II, if any color remained after the completion of the initial mixing time more thiosulfate was added and, mixed for 15 minutes. This sequence was repeated until the color had completely disappeared. Once the reaction of thiosulfate with the ferrate was complete, the pH was adjusted to the desired test condition.

After the appropriate pH was established, the mixing speed was slowed to about 60 rpm (+/- 5%). Alum was prepared as a dilute solution with a concentration of 40 grams per liter. The required amount of alum was then added to the reactor. The aluminum hydroxide floc formed instantly and the pH shifted. The pH was adjusted again while mixing continued.

The prescribed amount of organic polymer as a dilute solution of 2.0 mg/l was added to the reactor. Stirring was continued for 15 minutes at the slow speed of 60 rpm. The polymer solution was made up well in advance of its use to insure the polymer was completely dissolved.

After this final mixing period, the stirring was stopped, the covered beaker was set aside, and allowed to settle overnight before sampling.

3.3.4 Sampling and Analysis

The sampling of groundwater from the monitoring wells was conducted according to proper groundwater sampling protocol by Golder Associates, a subcontractor to the Environmental Restoration Program Division (ERPD) of EG&G, using operating procedure for groundwater sampling (OPS-GW-06, March 1992). Approximately 10 gallons of water were collected from each well in one gallon plastic bottles over a five day period. The samples were taken to Treatability Laboratory 264 in Building 881. No treatment of the water was done prior to its use

in this study. These samples were used to prepare the groundwater test solution used in this study and also used for the analysis done prior to the treatment studies reported herein.

Samples from the treated groundwater were collected the day following completion of each testing phase. The liquid above the settled solids was decanted into clean plastic bottles, sealed and sent for analysis. Accu-Labs Research Inc. of Golden Colorado analyzed the test samples for metals, radionuclides and several other parameters such as TSS, pH and hardness. Their mode of measurement, equipment used and the EPA approved analytical method are shown in Table 1.0-2.

3.4.1 Waste from This Study

Waste from this study will be about 70 liters of treated water plus the sludge produced during the treatment. Weight of dry solids from the sludge may be as much as 250 grams containing most of the metal contaminants and radionuclides.

3.4.2 Experimental Treatment Process

Techniques used during the experimental phases of this study were done to simulate the process described in Section 1.3.1. Since standard test techniques were used the results can be used to estimate full scale water treatment plant capital cost. However, this study was directed toward the process chemistry rather than to optimize the mechanical parameter. Additional test work will be required to minimize the equipment costs of a full scale plant.

3.5 DATA MANAGEMENT

All pertinent information collected for this study was recorded by ACTA Resources, Inc. personnel and by EG&G personnel in their respective notebooks. Accu-Labs Research, Inc. reported the analytical results in a typed report (see Appendix A) and the data was also archived by them. These data were input into a computer for use with the ECHIP software for evaluation and analysis. Much of the information generated with this program is presented in several appendices.

3.6 DEVIATION FROM THE WORK PLAN

Deviations from the work plan were minimal. The main reason for being able to conform to the work plan closely is that the work plan design allowed the second and third phases of the study to be planned after the completion and analysis of the results from the preceding work. Because the data was analyzed using the ECHIP, program it was felt that there would no personal bias in the interpretation of the results and there would be a definite direction to pursue in the subsequent tests.

4.0 RESULTS AND DISCUSSION

Each phase of the work will be discussed in detail. The conclusions reached in each phase of work will be presented. These conclusions were used to determine experimental procedure in the subsequent phase. A large amount of information was generated by the computer program, much of which will be displayed in the appendix rather than in the body of the report.

4.1 Phase I Results and Discussion

Fourteen tests were performed in Phase I following the procedures outlined in Section 3.3.3. This phase of the study was designed to examine the magnitude of the effects of four variables on the removal of 23 contaminants in the groundwater. To interpret and understand the data the ECHIP computer program was used. The values of the variables and the analytical results were input into the program. The pH values of the supernatant liquid as measured and reported by Accu-Labs were used rather than the values measured at the time of testing because it was believed that these were the true equilibrium values. Table 4.1-1 shows the test variables input to the computer.

Table 4.1-1 Phase I Variables in Test Matrix

Test No.	pH	Ferrate	Alum	Polymer
		log (mg/l)	mg/l	mg/l
1	8.2	1.895	50.0	5.00
1	8.3	1.895	50.0	5.00
4	8.2	1.895	10.0	0.5
6	8.4	1.196	50.0	0.5
8	8.2	1.196	10.0	5.00
11	9.7	1.673	30.0	2.75
10	8.3	1.196	10.0	0.50
17	7.6	-3.000	0.000	0.000
2	11.5	1.196	10.00	0.500
2	11.5	1.196	10.00	0.500
3	11.4	1.196	50.0	5.00
3	11.3	1.196	50.0	5.00
5	11.5	1.895	10.0	5.00
7	11.5	1.895	50.0	0.50
9	11.3	1.895	50.0	5.00

Analytical data was entered into the ECHIP program as shown in Table 4.1-2. Some discussion of this data is required. Of the 23 elements of concern analyzed, only those listed in the table had three or more values above the analytical detection limits. To define a response surface in this linear model at least three measured responses from analytical results were needed for the ECHIP program to calculate the coefficients in the linear equation. When using the feed solution (shown as test 17) as one point, the omitted elements still had fewer than three data points. As a

consequence of this, only the elements listed in Table 4.1-2 were examined in Phase I. Values of the analytical results reported below the analytical detection limits, for those examined, were entered into the table as zeros. The radionuclide values were entered even when negative, that is less than zero. This may over-estimate the effects, but since Phase I of this study is only a screening analysis, the conclusions drawn from this series of tests will not be affected. The radiochemical determinations for americium (Am) 241 and plutonium (Pu) 239-240 were reported in picoCuries per liter, pCi/l, total. The uranium (U) and all other elements' analytical results are reported in milligrams per liter, mg/l.

Table 4.1-2 Analytical Results for Phase I Ferrate Treatment Tests

Test	Am pCi/l	Pu pCi/l	U mg/l	Al mg/l	Ba mg/l	Cr mg/l	Fe mg/l	Se mg/l	Ag mg/l	V mg/l
1	-0.03	0.18	0.038	0.7	0.06	0.000	0.03	0.051	0.000	0.000
1	-0.06	0.17	0.037	0.7	0.06	0.000	0.03	0.047	0.000	0.000
4	0.01	0.21	0.039	0.2	0.08	0.000	0.04	0.047	0.005	0.000
6	-0.03	0.16	0.036	0.7	0.07	0.000	0.02	0.052	0.000	0.000
8	-0.02	-0.02	0.037	0.2	0.09	0.000	0.02	0.049	0.000	0.000
10	0.02	0.02	0.036	0.2	0.08	0.000	0.02	0.056	0.000	0.000
11	0.00	0.00	.0035	0.3	0.00	0.000	0.13	0.055	0.000	0.000
17	0.86	7.51	0.044	18.00	0.25	0.029	19.00	0.044	0.029	0.042
2	-0.06	0.17	.0024	0.0	0.00	0.000	0.78	0.055	0.005	0.000
2	-0.01	0.24	.0020	0.0	0.00	0.000	0.76	0.052	0.005	0.000
3	0.01	0.14	.0042	2.2	0.00	0.000	0.68	0.053	0.000	0.006
3	-0.05	0.23	.0035	1.7	0.00	0.000	0.90	0.052	0.005	0.005
5	-0.05	0.12	.0025	0.2	0.00	0.000	2.30	0.054	0.000	0.000
7	0.05	0.12	.0028	2.2	0.00	0.005	2.70	0.052	0.009	0.005
9	0.09	0.19	.0034	2.0	0.00	0.006	2.30	0.050	0.006	0.000

The information in Tables 4.1-1 and 4.1-2 was input into the ECHIP program and the data staticstically analyzed. The program creates numerous sets of out-put data. The program calculates the coefficients of the linear equation, estimates the fit of the data to the model and displays that data in two and three dimensional graphs. The program compares the calculated value to the actual data and further calculates a residual standard deviation. If this standard deviation differs from the standard deviation calculated from the analytical results of the replicate tests the computer signals "Lack-of-Fit" message (LOF).- Again, this is not serious in the screening design and will not affect the conclusions reached.

In the test matrix there were three tests run in duplicate, tests 1, 2 and 3. Duplicate tests were performed to estimate the standard deviation (SD) from test to test. The calculated SD from dublicate tests is shown in Tables 4.1-3 and 4.1-4, called Replicate SD. Also shown is the difference between the calculated values of the model and the actual test values, called Residual SD. If these two values are close there is a fit of the calcutated model to the data analyzed. If not, the model is said to have a LOF, which occurred in six of the ten elements where there was sufficient data. This is not unexpected, since the lineaer model used in Phase I is a screening model. Additional information is presented in these tables, but is insignificant to the conclusions of Phase I.

Figure 4.1-1 Summary of Results of Phase I Tests Using ECHIP Program

PROJECT NAME: RF3.ECP
Created: Thu Oct 27 14:02:54 1994
Summary results

Element	pH	logferrate	alum	polymer
As	***	***	***	***
Pu	***	***	***	***
U	***	***	***	***
Al	***	***	***	***
Ba	***	***	***	***
Cr	***	***	***	***
Fe	***	***	***	***
Se	***	***	***	***
Ag	***	***	***	***
V	***	***	***	***

LOF LOF LOF LOF LOF LOF LOF LOF

Figure 4.1-1 is the first table output from the ECHIP program showing the effect of individual variables upon the constituent listed. The number of stars indicate the relative effect of the test variables, that is, the more stars, the greater the effect of that variable upon the element's concentration is solution. The data in Figure 4.1-1 shows that polymer and alum addition had little or no effect upon the elements. Ferrate had a major impact upon eight of the ten constituents and pH was the major test variable effecting the removal of uranium and barium.

Two examples of the numerical data generated by the ECHIP program are shown in Tables 4.1-3 and Table 4.1-4 and discussed herein. A complete set of ECHIP data output is presented in Appendix B.

Table 4.1-3 Coefficients for Response of Americium

«xxxxxxxxxxxx» Coefficients for response 'Am'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.332844			0	CONSTANT
-0.00477232	0.0165708	0.7792-	0.943	1 pH
-0.177047	0.0250332	0.0000	0.847	2 logferrate
0.000793209	0.00147026	0.6013-	0.841	3 alum
-0.00197069	0.0130205	0.8827-	0.866	4 polymer

N trials = 15

N terms = 5

Residual SD = 0.096570, Lack-Of-Fit P=0.0373 *

Residual DF = 10

Residual SD used for tests

Replicate SD = 0.034157

Replicate DF = 3

R Squared = 0.872, P=0.0002 ***

Adj R Squared = 0.821

Table 4.1-5 Coefficients for Response of Uranium

«xxxxxxxxxxxx» Coefficients for response 'U'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
--------------	----	---	-----------	------

0.0179644			0	CONSTANT
-----------	--	--	---	----------

-0.0105585	0.000952577	0.0000	0.943	1 pH
------------	-------------	--------	-------	------

-0.000472097	0.00143904	0.7496	0.847	2 logferrate
--------------	------------	--------	-------	--------------

1.23131e-005	8.45186e-005	0.8871	0.841	3 alum
--------------	--------------	--------	-------	--------

5.29126e-005	0.000748485	0.9450	0.866	4 polymer
--------------	-------------	--------	-------	-----------

N trials = 15

N terms = 5

Residual SD = 0.005551, Lack-Of-Fit P=0.0007 ***

Residual DF = 10

Residual SD used for tests

Replicate SD = 0.000524

Replicate DF = 3

To discuss these results the equation used for this analysis must be recalled; it is:

$$y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4$$

Coefficients a_0 through a_4 are shown in Tables 4.1-3 and 4.1-4 for each variable parameter and x_1 is pH, x_2 is ferrate, x_3 is alum and x_4 is polymer all in units of mg/l. A sign is assigned to the coefficients so it can be determined if the concentration of the particular element increases or decreases as the concentration of the reagent changes.

In the case of Am 241 the largest coefficient, other than the constant, is for logferrate and is minus. This means that the addition of ferrate will cause a decrease in the concentration of americium. The coefficients of the other reagents are two to three orders of magnitude smaller. Therefore, these reagents will have little or no effect on the concentration of americium in the water. Figure 4.1-2 displays the system. There is a large reduction of the metal concentration as more ferrate is added, but as pH is increased little or no effect is observed.

From the general chemistry, it would be expected that as the pH rises, americium would form an hydroxide and as a solid phase be removed more effectively. This not being the case leads to a question. What is wrong with the test procedure or does ferrate increase the solubility of americium in basic solutions? Examination of the other elements' responses show this same discrepancy, especially iron. Refer to Appendix B.

The only exceptions are barium and uranium. Table 4.1-4 for uranium shows only pH had any effect upon the removal of uranium. This is what should be expected in aqueous chemistry.

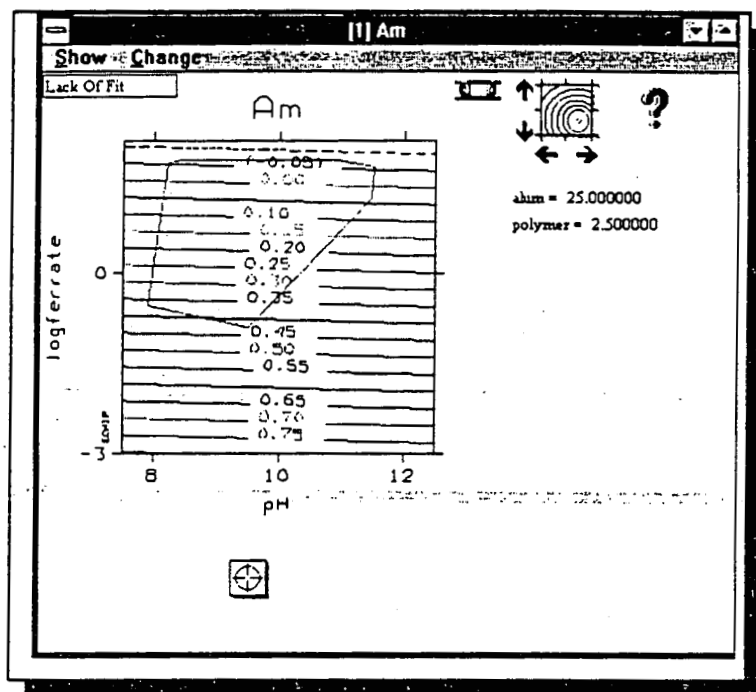
In reviewing the data in Appendix B, several interesting features are noted. First, those elements, Al, Cr and Fe, which are known to precipitate as the pH of the solution rises and should have been removed more effectively did not follow the principals of general chemistry. However, they did decrease with ferrate addition. It appears that these three elements have the same response, that is they are tied together some how. Also, the response of americium and plutonium

are similar but with a very slight response to increasing pH. Since these results are completely unexpected, other factors, such as test techniques, were examined to explain this phenomenon. Observations made during testing were documented and reviewed. The only factor found that could have caused this problem was that at high pH, the ferrate ion was not completely reduced in the reaction time allowed in Phase I. This was obvious, since the purple color of the ferrate ion was still present in the solution. The next day, when the solution was decanted for analysis, those test which had the purple color then had a yellow cloudy appearance. This indicated that some iron compounds had not settled out of the solution. The chemical analysis confirm this. It is

In an attempt to get some information from this phase of the study the, data for those tests where no color was seen were used along with the feed solution analysis, Test No. 17, in the ECHIP program. These tests were 1,1,4,6,8,10, and 11. The feed solution is entered as test 17. Results of these calculations are given in Table 4.1-4 which shows less lack of fit. Several items must be noted about this set of data: 1) the pH range is very small, 7.4 to 9.7, 2) elements Cr,Co,Cu, and Zn had no analyzed values above the analytical detection limits in the test region and should be ignored.

It was seen that many of these elements were removed by potassium ferrate alone; these include Am, Pu, Al and Fe. The other elements had mixed responses. Barium was removed by a combination of pH and ferrate and uranium was removed by pH, but its' concentration rose as the ferrate concentration rose. Last, the removal of silver was lowered by ferrate, but its' concentration rose with increasing pH. Computer output of this data analysis is presented in Appendix C. However, one example of the response where ferrate did aid in removal is presented for clarification. Figure 4.1-3 is the response surface of americium that shows a strong correlation of removal to the amount of ferrate added to the solution. Plutonium, aluminum, and iron had responses that were very similar.

Figure 4.1-2 Response Surface of Americium



4.1.1 Conclusions from Phase I Tests

Several conclusions can be made from this data, which leads us to the Phase II of this study.

These conclusions are:

- 1) Ferrate alone does lower the concentration of several of the contaminants of concern from the RFP groundwater, at least Am, Pu, Al, Fe, and possibly Cr, at pH values below 9.7

- 2) Removal of contaminants is more effective when all of the ferrate is eliminated by chemical reduction during treatment
- 3) Chemical reduction of ferrate is more difficult at pH greater than 9.7, requiring longer mixing times in the reactor
- 4) Several elements show mixed response, where both pH and ferrate concentration affect the final concentration after treatment. These include Ba, Ag, and U, with U having negative response to ferrate addition and silver showing an increase in concentration as the pH rises
- 5) Changing the concentration of both alum and polymer has a very slight affect upon the removal of any of the contaminants of concern; however, the observations suggest that a minimum amount is required.

These conclusions lead to the second phase of the study. It's obvious that the pH range must be expanded. Therefore, more time for degradation of the ferrate will be allowed and before the test is completed all of the ferrate color must be gone. Since the elements had different responses to the treatment, an optimum treatment condition must be sought that will maximize the removal of all the contaminants.

4.2 Phase II Results and Discussion

According to the work plan, the second phase test design was to be developed based upon the results of the first phase and to lead to the overall objective of the entire study. The second phase objectives are to minimize reagent consumption and still produce acceptable treated water for discharge. The acceptable level of contaminants in the treated water must meet the CWQCC discharge limits listed in Table 1.0-1.

It is, also understood that only a single process is to be considered in this study. This means that a single set of treatment parameters must be found that will satisfactorily remove most if not all of the contaminants of concern, with special emphasis on the radionuclides. Phase I results showed a limited response to the ferrate treatment over the narrow pH range where the data was valid. The radionuclides of americium and plutonium were both removed with ferrate additions, but uranium was not affected. Data from Phase I did not show a common point where that the initial four variables could be adjusted for the removal of all the elements. Secondary treatment was not considered as part of the process investigated in this study, even though this would certainly improve the water quality.

Phase I, a screening study, did indicate that above a certain minimum concentration both alum and polymer had no effect upon the removal of the dissolved metals in solution. Therefore, these two variables will be constant in the Phase II test design.

It was determined in Phase I that there is interaction between ferrate and pH upon the response of several metals during treatment. Both will be variables to be examined in this phase. These two variables, pH and ferrate, will be tested over a broad range to determine, if in fact, a common point does exist in the system to remove most, if not all, of the contaminants in the water. The dosing of

ferrate studied in the Phase II tests will range from 0 to approximately 160 mg/l. The pH range to be examined will be from the initial pH of the water as received through 11.5.

Responses of the metal removal as a function of the variables and the variable interactions, pH and ferrate, are to be statistically analyzed in a model that is capable of determining those interactions. Therefore, even though there are only two variables, a large number of tests are required to gather sufficient data to estimate the interaction terms in any model chosen. In addition, replicate tests are needed to estimate the statistical variations from test to test.

Using the ECHIP program, it was determined that a minimum number of tests, 13 to 18, is needed

~~to satisfy the models to correctly estimate the variable interaction. Five replicate tests were~~
recommended by the program. To save time and analytical costs it was decided that three replicate tests would be sufficient. In addition, several Phase I tests could be used for supplemental replication. The Phase II study will examine 15 tests, which will satisfy the criteria of any of the models available in the ECHIP program. Table 4.2-1 shows the test matrix developed by the program.

As was true in Phase I, the tests were conducted in the order presented in the test matrix to eliminate any systematic errors that might be introduced by the experimenter. Alum and polymer will be held constant at 10 mg/l and 5.0 mg/l, respectively, during each test in the second phase of this study. Thiosulfate will be added in sufficient quantity to eliminate the purple color in several stages of mixing, 15 minutes each.

Phase II laboratory work was done September 14 and 15, 1994 in Building 881, Room 264. The treated solution was decanted the day after completing the test into plastic bottles, sealed, labeled

and sent to Accu-Labs for analysis of both the inorganic and radionuclide contaminants. The complete analytical report is in Appendix A.

Table 4.2-1 Phase II Test Matrix

Trial Number	pH	log Ferrate	Ferrate, mg/l	Comments
3	7.80	2.200	158.5	As received
4	8.81	1.576	37.7	
12	9.65	2.2	158.5	
11	9.63	1.069	11.7	
9	11.5	0.000	1.0	
1	11.50	2.200	158.5	
2	11.50	1.100	12.6	
8	9.65	2.200	158.5	
1	11.50	2.200	158.5	
10	10.45	0.602	4.0	
2	11.50	1.100	12.6	
13	10.00	1.100	12.6	
14	11.5	-3.000	0.0	0 mg/l Ferrate
16	10.00	2.200	158.5	
17	8.0	-3.000	0.0	Feed Sol'n

Upon receiving the analytical results, the data was input into the computer Response Table of the ECHIP program for analysis. As before, the pH values reported by Accu-Labs were used in the test matrix for the data analysis. Using these reported values had the effect of changing the test matrix because of some significant shifts in the pH. The reason for the pH differences is unknown. There were seven tests from Phase I that were included into the Phase II matrix prior to analysis. These tests had different amounts of alum and polymer added, but because these

two variables had little or no effect upon the removal of the contaminants, they were acceptable for use in the Phase II modified test variable matrix. The feed solution from Phase I and II are also included in the matrix. This combined matrix was used to analyze the performance of ferrate treatment technology to eliminate contaminants of concern from RFP groundwater. The matrix is presented in Table 4.2-2.

The analytical response table used for the analysis of the second phase work is displayed in Table 4.2-3.

As in Phase I only those elements that had a sufficiently large number of responses above the analytical detection limits were input into the program. Also, the responses whose analytical results were reported below the detection limits are entered into this table as zeros. The radionuclides' data were entered into the table as reported, even when that value was negative. Using zero values may over estimate the response but because of the large number of tests used, the impact on data analysis is not believed to be significant. This can be demonstrated because the residual standard deviation for these tests is large when compared to the analytical detection limits. For example, the analytical detection limit is 0.05 mg/l for aluminum and the residual standard deviation calculated is 0.437. This means that whatever the true concentration of the metal element is in the treated water below the detection limit, the value would not effect the results of the computer analysis of the data.

Table 4.2-2 Modified Phase II Test Matrix

Trial Number	pH	log(mg/l ferrate)	Comments
1	11.4	2.200	Phase II Test 1
1	11.4	2.200	Phase II Test 1
2	11.8	1.100	Phase II Test 2
2	11.8	1.100	Phase II Test 2
3	8.5	2.200	Phase II Test 3
4	8.6	1.576	Phase II Test 4
8	9.4	2.200	Phase II Test 0, on analytical report
9	11.6	0.000	Phase II Test 9
11	9.6	1.069	Phase II Test 11
12	9.8	2.200	Phase II Test 12
13	10.2	1.100	Phase II Test 13
12	10	2.2	Phase II Test 16
17	8.0	-3.000	Phase II Feed Solution, untreated
18	8.2	1.895	Phase I Test 1
18	8.3	1.895	Phase I Test 1
19	8.4	1.196	Phase I Test 6
19	8.3	1.196	Phase I Test 10
20	9.7	1.673	Phase I Test 11
10	10.1	0.602	Phase II Test 10
14	11.9	-3.000	Phase II Test 14
17	7.4	-3.000	Phase I Feed Solution
19	8.2	1.196	Phase I Test 8
18	8.2	1.895	Phase I Test 4

Table 4.2-3 Analytical Results for the Modified Phase II Ferrate Treatment Tests

Test	Am	Pu	U	Al	Ba	Cr	Co	Cu	Fe	Se	Ag	Zn
	pCi/l	pCi/l	mg/l									
8	0.03	0.17	0.020	0.2	0.0	0.008	0.0	0.0	0.05	0.058	0.008	0.0
1	0.01	0.15	0.0011	0.5	0.0	0.009	0.0	0.0	0.08	0.055	0.010	0.0
1	0.03	0.12	0.0012	0.4	0.0	0.006	0.0	0.0	0.13	0.056	0.007	0.0
2	0.02	0.15	0.0039	0.1	0.0	0.000	0.0	0.0	0.19	0.056	0.005	0.0
2	0.01	0.12	0.0015	0.0	0.0	0.000	0.0	0.0	0.26	0.059	0.007	0.006
3	0.04	0.96	0.034	0.0	0.07	0.011	0.0	0.0	0.0	0.049	0.009	0.0
4	0.02	0.22	0.030	0.0	0.08	0.008	0.0	0.0	0.0	0.059	0.011	0.0
9	0.04	0.08	0.0018	0.0	0.0	0.000	0.0	0.0	0.07	0.054	0.000	0.0
10	0.03	0.13	0.0069	0.0	0.0	0.000	0.0	0.0	0.02	0.065	0.000	0.0
11	0.00	0.15	0.027	0.0	0.0	0.000	0.0	0.006	0.02	0.061	0.005	0.0
12	0.02	0.30	0.025	0.0	0.0	0.000	0.0	0.0	0.02	0.059	0.007	0.0
13	0.08	0.00	0.022	0.0	0.0	0.000	0.0	0.0	0.02	0.059	0.008	0.0
12	0.03	0.15	0.0077	0.0	0.0	0.0	0.0	0.0	0.05	0.056	0.009	0.0
17	1.10	6.70	0.036	20.0	0.25	0.025	0.006	0.023	19.00	0.040	0.026	0.081
14	0.08	1.8	0.022	0.0	0.0	0.000	0.008	0.0	0.02	0.056	0.000	0.000
18	-0.03	0.18	.038	0.7	0.06	0.00	0.00	0.00	0.03	0.051	0.000	0.0
18	-0.06	.17	.037	0.7	0.06	0.00	0.03	0.02	0.03	0.047	0.000	0.0
19	-0.03	0.16	.036	0.7	0.07	0.00	0.00	0.00	0.02	0.052	0.000	0.0
19	0.02	0.02	0.036	0.2	0.08	0.00	0.00	0.00	0.02	0.056	0.000	0.0
20	0.00	0.00	0.0035	0.3	0.00	0.00	0.00	0.00	0.13	0.055	0.000	0.0
17	0.86	7.5	0.044	18	0.25	0.020	0.007	0.029	19	0.044	0.029	0.086
19	-0.02	-0.02	0.037	0.2	0.09	0.00	0.00	0.00	0.02	0.049	0.000	0.0
18	0.01	0.21	0.039	0.2	0.08	0.00	0.00	0.00	0.04	0.047	0.005	0.00

Three mathematical models were used to analyze the data. The partial cubic model fit the data well and uses the following equation:

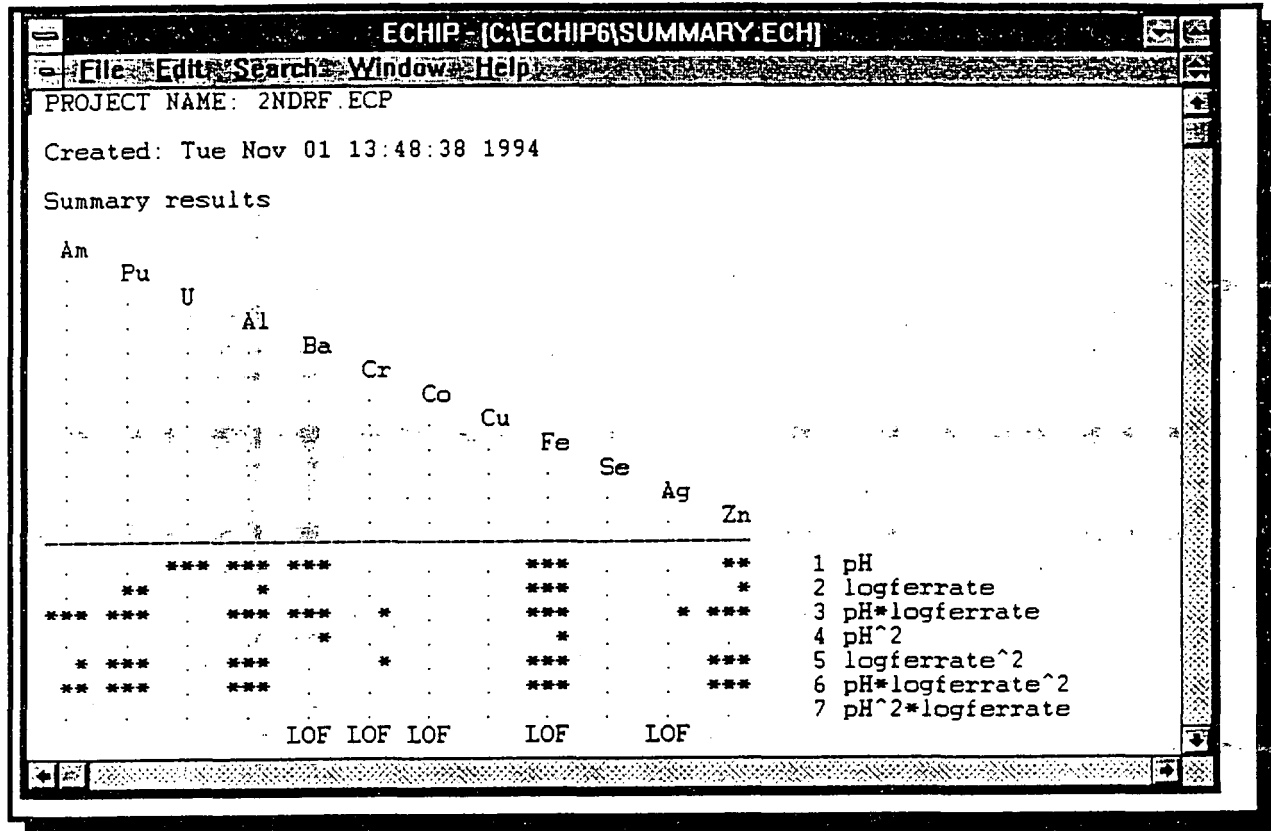
$$y = a_0 + a_1 x_1 + a_2 x_2 + a_{12} x_1 x_2 + a_{11} x_1^2 + a_{22} x_2^2 + a_{112} x_1^2 x_2 + a_{122} x_1 x_2^2$$

In this equation y is the concentration of the metal ion in solution and x_1 is the pH and x_2 is the log of the concentration of potassium ferrate in mg/l.

The ECHIP program generates substantial amounts of information which is not germane to the study but may be of interest to those who want to examine such factors as the robust nature of the results or other statistical information. The complete output for the partial cubic model is presented in Appendix D. Figure 4.2-1 is the first of the computer outputs showing the effects of the variables, pH and ferrate, upon the metals. In this table the number of asterisks under each element and to the side of a particular factor indicate the relative effect. This does not give the absolute magnitude or sign of the effect.

There is a lack of fit using this model for only five of the contaminants Zn, Se, Fe, Cu and Co. It is not unexpected that there is a lack of fit for Zn, Cu and Co because there are so few data points in the response matrix. The lack of fit for selenium is due to the fact that the ferrate treatment system does not have an impact on the removal of selenium. There is no explanation for the lack of fit for iron, but could be attributed to the addition of iron to the experiment, causing a different response and thus requiring a different model to analyze. Notice the strong interaction of pH and ferrate as indicated by the number of asterisks in the third row, 3 pH*logferrate, Figure 4.2-1.

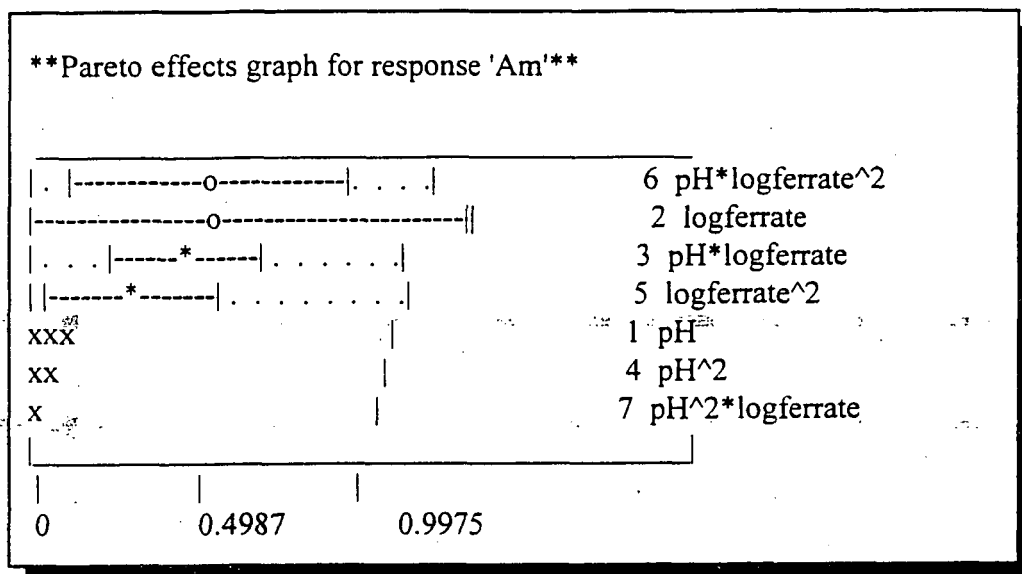
Figure 4.2-1 Summary of Results of Phase II Tests Using ECHIP Program



To determine the magnitude and sign of the coefficients of the variables, the Pareto Graphs are very useful. Several of these are presented here to point out the effect of ferrate upon the removal of the contaminant and the interaction with pH, both of which combined, produce a more effective metals removal than either by itself. In Figure 4.2-2 the Pareto Graph is presented for americium. Notice that the effects are in descending order of the absolute effects.

The effects are scaled to the units of the response, in this case pCi/l. The line represents the 95% confidence limit and as can be seen, it is very broad compared to the magnitude of the effect.

Table 4.2-2 Pareto Effects Graph of Americium



This is due to experimental error, both testing and analytical, and it is not possible to separate the two in this study. The " * " in the line is for a positive coefficient and the " o " is for a negative response. Those factors with " x " only, no line, has an effect so small it can be eliminated from consideration.

For americium, it is obvious that ferrate addition is needed to reduce its' concentration in solution because the effect of logferrate and pH*logferrate² are negative. As these two values increase, the concentration of americium decreases. Notice that pH and pH² have little or no effect upon americium, which confirms what was observed in Phase I.

Figure 4.2-3 Response Surface of Americium

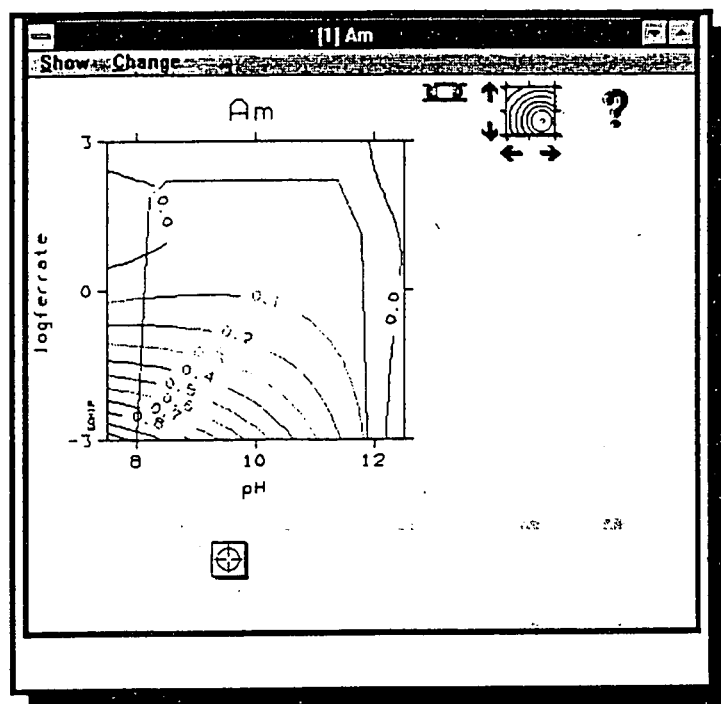


Figure 4.2-3 presents the response surface of americium. This figure shows the response surface calculated from the equation generated by the computer analysis of the test data. The contours in this figure are approximately one standard deviation apart. The series of lines that cross the contours is essentially the experimental region.

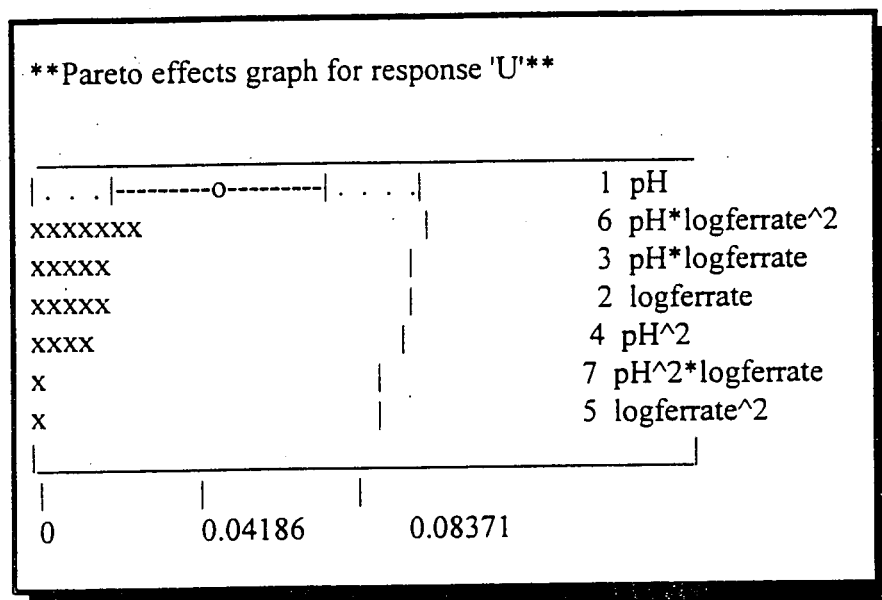
By reviewing the information in Appendix D it can be seen that the responses are similar for groups of elements. Uranium and barium have similar response surfaces and are more dependent upon pH than are the other elements. Americium and plutonium have similar removal responses, which are dependant on ferrate. Cr, Co, Cu, and Ag are similar having a rather complex response. Selenium shows a response very different from any of the other contaminants in that there is a maximum in the center of the field of investigation. It is possible that this is due to the fact that there are more data points in this region so the average is higher. Fe, Al and Zn are similar in

their response to the interaction of ferrate and pH.

The Pareto Graph for uranium is shown in Figure 4.2-4. It can be seen that pH was the only major factor that removed it from solution. All of the other factors were of no importance.

Barium is similar but with some interaction of the two variables.

Figure 4.2-4 Pareto Effects Graph of Uranium



The Pareto Graph of Al shows the strong effect of ferrate upon its' removal from solution, but with more interaction of the variables. Figure 4.2-5 shows that pH*log ferrate has a strong positive effect, that is the concentration of Al in solution will increase as the product of these two variables increases. However, the second term logferrate has a strong negative effect, therefore, it is obvious which variable to manipulate. From the Pareto Graph its impossible to picture what actually does occur. It is much easier to intrepret this system using the two dimensional graph, Figure 4.2-6.

Figure 4.2-5 Pareto Effects Graph of Aluminum

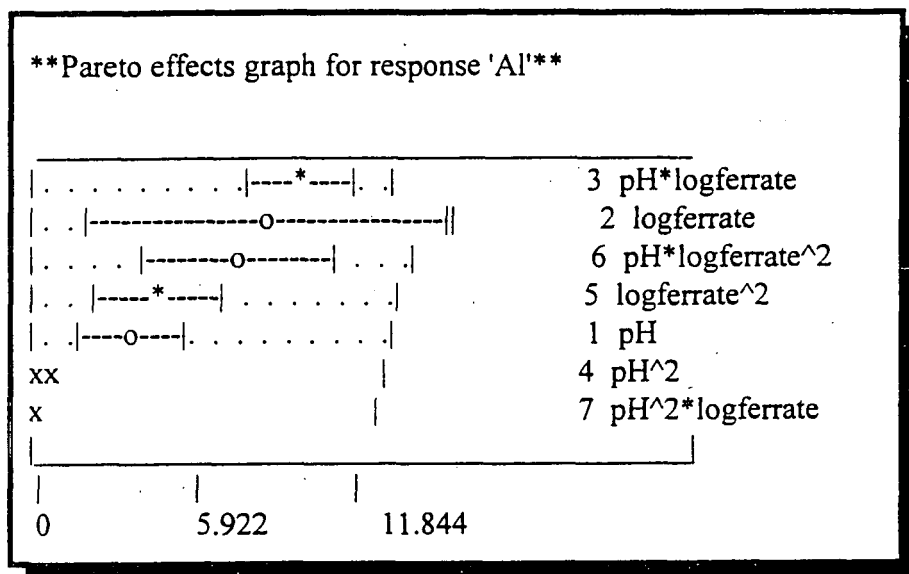
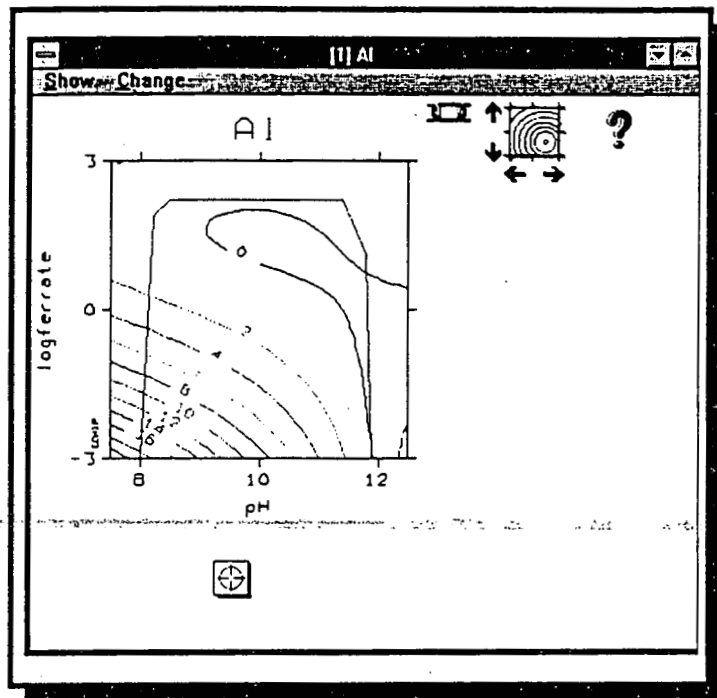
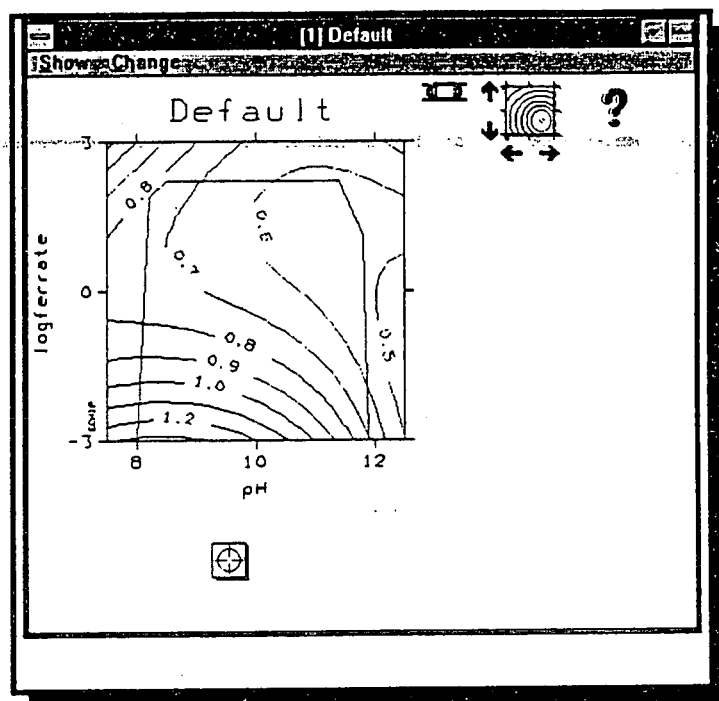


Figure 4.2-6 Aluminum Response to Ferrate Treatment



The contaminants of concern, except selenium and possibly silver, are removed by the ferrate treatment process. Levels below the CWQCC discharge limits were achieved in a common region of all the metal tests, except for selenium and silver. The next task becomes one of identifying that region. Again the ECHIP program is used to accomplish this goal. The

Figure 4.2-7 Contour Plot of Combined Metals Responses



program allows for each metal response to be combined and analyzed. A graph is then produced that displays the optimum common region that will maximize the removal of all the elements. To combine the responses they were weighted based upon the CWQCC discharge criteria. This weighting factor was simply one divided by the allowable discharge concentration. Therefore, the

52

optimum value in the combined response contour plot should have a value of one if all of the discharge limits were met exactly for each element. If the value was very small then there would be some assurance that all the elements had met the discharge limits because none would be close to the limits. Figure 4.2-7 shows the contour plot of the combined responses.

The optimum conditions selected are pH 10.35 and logferrate 1.02. At this point the calculated combined response is 0.58. It is not possible to say that all the contaminants met their individual limits but, on the average, the elements are below the CWQCC discharge limits. Since an average is not good enough, each individual limit must be met. Therefore, the optimum condition picked from the combined response contour plot, Figure 4.2-7, was checked on each individual plot to get a predicted concentration at this set of conditions. The results are shown in Table 4.2-4.

In Table 4.2-4 there are 13 metals for which the predicted results are below the CWQCC discharge limits. Four of the elements have CWQCC discharge limits that are below the analytical detection limits; therefore, it is not known if the discharge limits were met.

Notice that the 95 % confidence limit range is rather broad. This means that the predicted value has a 95 % probability that it falls within this range and not at the predicted value at that point.

Therefore, tests are required to confirm these results which lead to Phase III. However, the results show that ferrate water treatment technology can treat the RFP groundwater to discharge standards with the possible exceptions of selenium and silver.

Table 4.2-4 Predicted Contaminant Concentrations at the Optimum Conditions

	Predicted Results				CWQCC Discharge Limits	Meets Discharge Limits
	At Optimum	95 % Confidence Range				
Elements		Low Level	High Level	Units		
Americium	0.032	-0.089	0.153	pCi/l	0.05	Yes
Plutonium	0.04	-0.48	0.56	pCi/l	0.05	Yes
Uranium	0.0107	-0.0048	0.0262	mg/l		
U (Calc)	0.357	-0.160	0.873	pCi/l	5-10	Yes
Aluminum	-0.09	-1.13	0.940	mg/l	0.087	Yes
Barium	-0.008	-0.035	0.020	"	1	Yes
Chromium	0.0007	-0.0078	0.0091	"	0.05	Yes
Cobalt	-0.0008	-0.0169	0.0153	"	0.05	Yes
Copper	0.0007	-0.0109	0.0153	"	NA	?
Iron	-0.06	-0.32	0.21	"	0.3	Yes
Selenium	0.0613	0.0539	0.0686	"	0.01	No
Silver	0.0038	-0.0044	0.0121	"	0.0006	No
Zinc	-0.0004	-0.0043	0.0035	"	0.35	Yes
Element Reported Below ADL			Analytical Detection Limits (ADL) mg/l			
Beryllium			0.005	0.004	?	
Cadmium			0.005	0.0015	?	
Manganese			0.005	0.56	Yes	
Nickel			0.02	0.125	Yes	
Vanadium			0.005	0.1	Yes	
Antimony			0.05	0.024	?	
Arsenic			0.005	NA	?	
Lead			0.005	0.028	Yes	
Mercury			0.0001	0.00001	?	

The element selenium did not respond to this process since it exists as an anion in these solutions. The selenium anion cannot form an insoluble solid phase under these conditions. Therefore, it cannot be expected to be removed by this water treatment method because the technique used depends upon the formation of a solid phase containing the contaminant of concern. Selenium can be changed by a simple pretreatment step into a form that can be removed by the treatment process tested in this study.

Silver, the other element that was not removed satisfactorily, can be eliminated by a minor modification to the process. In this test program, thiosulfate was used to reduce excess ferrate and

~~it is the thiosulfate which caused the problem with silver. Silver forms a strong soluble complex of~~
thiosulfate. Excess thiosulfate would hold silver in solution. This problem can be overcome by using a reductant that does not complex the metals of interest. Sulfurous acid, SO_2 dissolved in water, would be a suitable alternative.

4.2.1 Conclusions from Phase II Tests

Phase II results show that ferrate does remove and aid in the removal of many metal ions from solution. The ferrate treatment process produces water that meets or very closely approaches the CWQCC discharge limits. The technology is simple and easy to apply in conventional water treatment plants. The specific conclusions from this phase of the work are:

- 1) Ferrate does remove metal ions from solution such as americium and plutonium

- 2) The pH variable is effective in removing some metal ion from solution such as uranium
- 3) Many metal ions have mixed response to both pH and ferrate such as chromium, cobalt and copper

There are many other conclusions that can be made from the details of the data presented in the computer analyzed output, which are presented in the Appenices B, C and D. These other minor conclusions do not have any impact upon the general conclusion that RFP groundwater can be cleaned to levels well within the CWQCC discharge limits, even when allowing for the statistical

~~deviation of the analytical results. Potassium ferrate technology is a tool that can be used to~~
process aqueous solutions contaminated with radionuclides and inorganic elements which are generated at the RFP site.

4.3 PHASE III RESULTS AND DISCUSSION

(To Be Written After Receipt Of Phase III Results)

APPENDIX A

(ANALYTICAL DATA TO BE INCORPORATED)

12

PHASE I ECHIP OUTPUT

APPENDIX B

PROJECT NAME: RF3.ECP

Created: Thu Oct 27 14:02:54 1994

Summary results

Am										
.	Pu									
.	.	U								
.	.	.	Al							
.	.	.	.	Ba						
.	.	.	.	.	Cr					
.	.	.	.	.	.	Fe				
.	.	.	.	.	.	.	Se			
.	.	.	.	.	.	.	.	Ag		
.	.	.	.	.	.	.	.	.	V	
<hr/>										
.	.	***	.	***
***	***	.	***	***	***	***	.	***	***	.
.
.
LOF	LOF	LOF	LOF			LOF				LOF

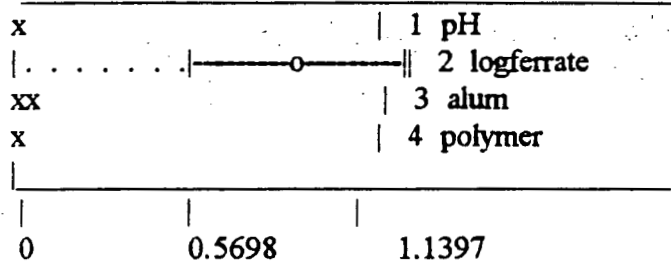
- 1 pH
- 2 logferrate
- 3 alum
- 4 polymer

PROJECT NAME: RF3.ECP

Created: Thu Oct 27 14:02:47 1994

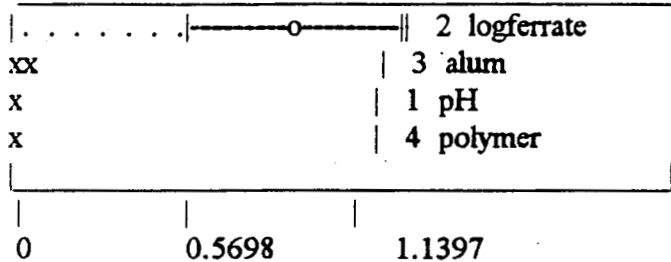
«xxxxxxxxxxxxxxxx» Effects graph for response 'Am'

LACK-OF-FIT



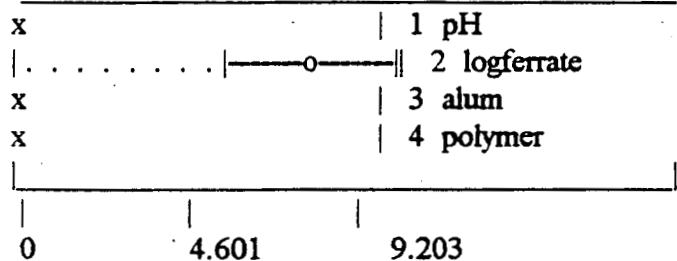
Pareto effects graph for response 'Am'

LACK-OF-FIT



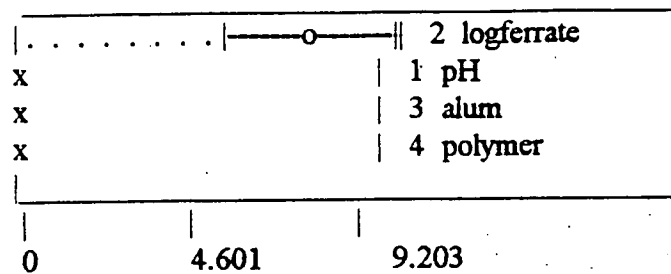
«xxxxxxxxxxxxxxxx» Effects graph for response 'Pu'

LACK-OF-FIT



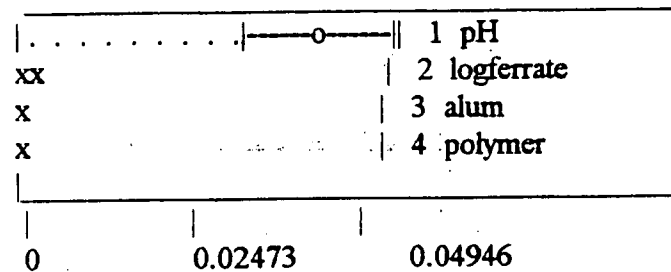
****Pareto effects graph for response 'Pu'****

LACK-OF-FIT



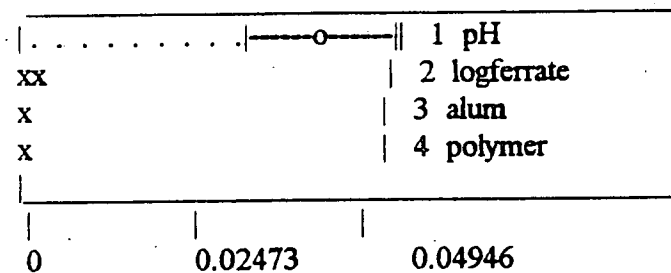
«xxxxxxxxxxxxxxxx» Effects graph for response 'U'

LACK-OF-FIT



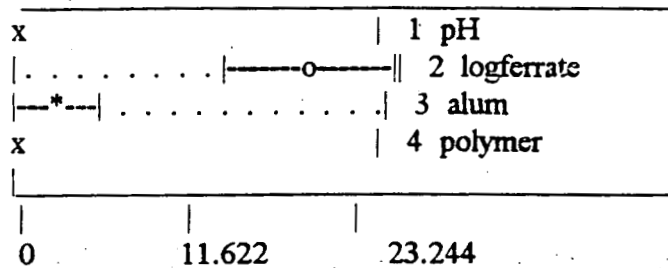
****Pareto effects graph for response 'U'****

LACK-OF-FIT



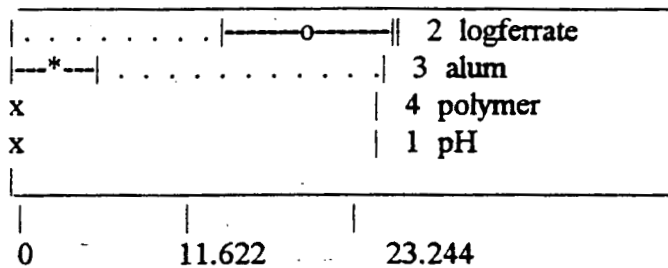
«xxxxxxxxxxxxxxxx» Effects graph for response 'Al'

LACK-OF-FIT

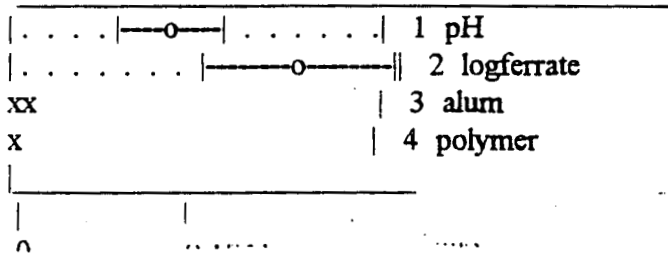


Pareto effects graph for response 'Al'

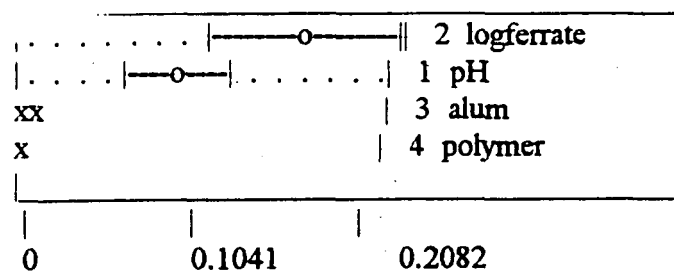
LACK-OF-FIT



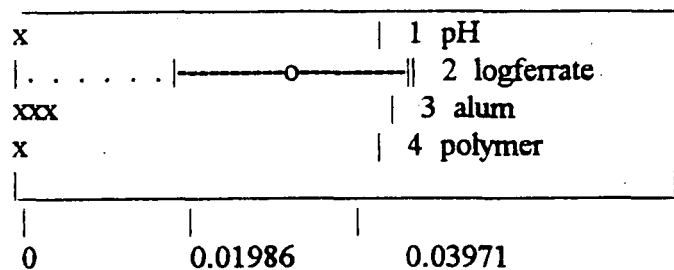
«xxxxxxxxxxxxxxxx» Effects graph for response 'Ba'



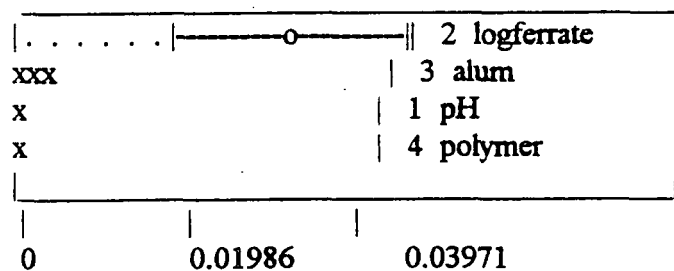
graph for response 'Ba'***



«xxxxxxxxxxxx» Effects graph for response 'Cr'

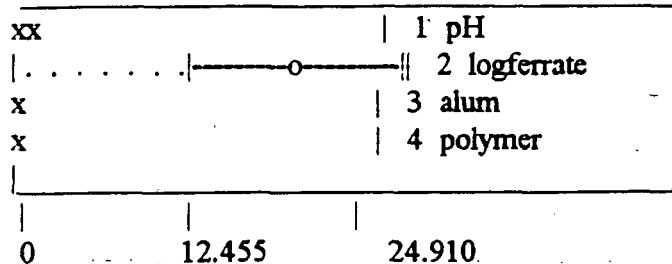


Pareto effects graph for response 'Cr'*



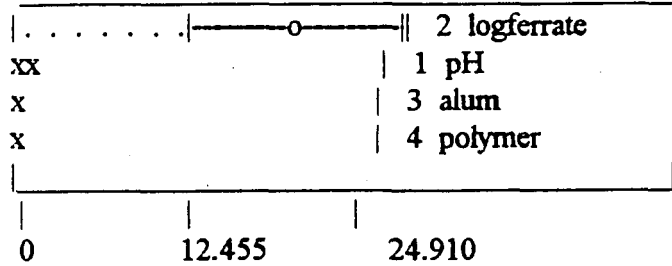
«xxxxxxxxxxxxxxxx» Effects graph for response 'Fe'

LACK-OF-FIT

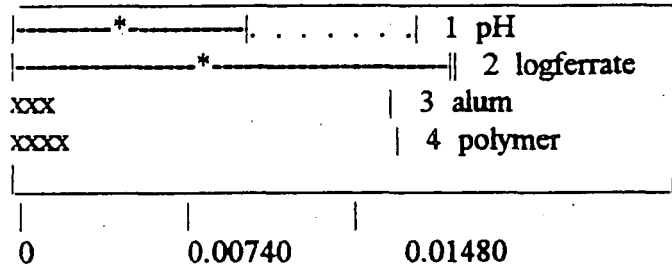


Pareto effects graph for response 'Fe'

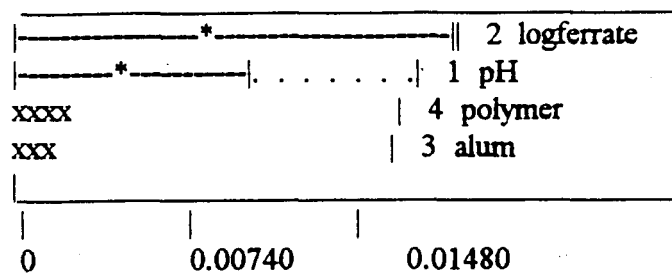
LACK-OF-FIT



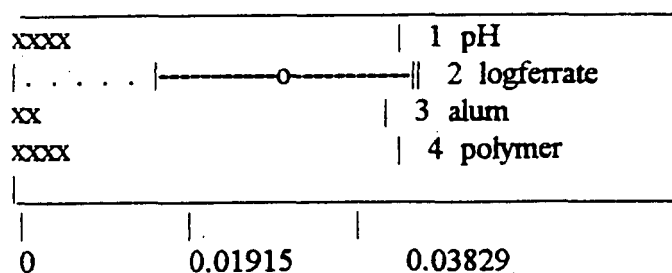
«xxxxxxxxxxxxxxxx» Effects graph for response 'Se'



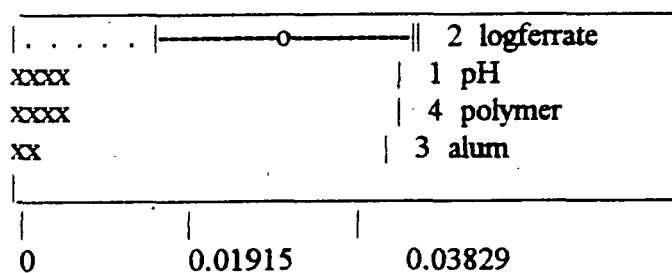
****Pareto effects graph for response 'Se'****



«xxxxxxxxxxxxxxxx» Effects graph for response 'Ag'

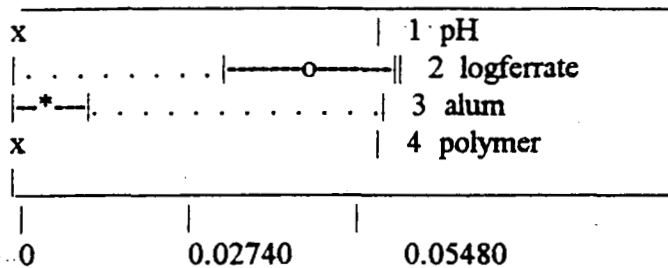


****Pareto effects graph for response 'Ag'****



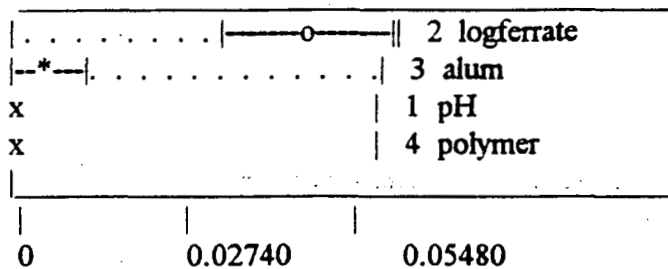
«xxxxxxxxxxxx» Effects graph for response 'V'

LACK-OF-FIT



Pareto effects graph for response 'V'

LACK-OF-FIT



PROJECT NAME: RF3.ECP

Created: Thu Oct 27 14:02:43 1994

«xxxxxxxxxxxxxx» Effects for response 'Am'

LACK-OF-FIT

EFFECTS RESLTN SIG TERM

0.3328		0	CONSTANT
-0.0186	0.1626	1	pH
-0.8666	***	2	logferrate
0.0397	0.2035	3	alum
-0.0099	0.1549	4	polymer

Residual SD = 0.096570

Replicate SD = 0.034157

N terms = 5

N unique trials = 12

N replicates = 3

N total trials = 15

«xxxxxxxxxxxxxx» Effects for response 'Pu'

LACK-OF-FIT

EFFECTS RESLTN SIG TERM

3.068		0	CONSTANT
-0.211	1.146	1	pH
-7.429	***	2	logferrate
0.188	1.252	3	alum
0.100	1.043	4	polymer

Residual SD = 0.627420

Replicate SD = 0.046726

N terms = 5
N unique trials = 12
N replicates = 3
N total trials = 15

«xxxxxxxxxxxxxx» Effects for response 'U'

LACK-OF-FIT

EFFECTS RESLTN SIG TERM

0.01796		0	CONSTANT
-0.04118	***	1	pH
-0.00231	0.01801	2	logferrate
0.00062	0.01003	3	alum
-0.00026	0.00860	4	polymer

Residual SD = 0.005551

Replicate SD = 0.000524

N terms = 5
N unique trials = 12
N replicates = 3
N total trials = 15

«xxxxxxxxxxxxxx» Effects for response 'Al'

LACK-OF-FIT

EFFECTS RESLTN SIG TERM

7.999		0	CONSTANT
0.092	2.483	1	pH
-18.712	***	2	logferrate
1.891	4.610	3	alum
0.392	2.800	4	polymer

Residual SD = 1.602920

Replicate SD = 0.204124

N terms = 5
N unique trials = 12
N replicates = 3
N total trials = 15

«xxxxxxxxxxxx» Effects for response 'Ba'

EFFECTS RESLTN SIG TERM

0.0960		0	CONSTANT
-0.0925	***	1	pH
-0.1633	***	2	logferrate
-0.0081	0.0351	3	alum
0.0019	0.0258	4	polymer

Residual SD = 0.015913
Replicate SD = 0.000000

N terms = 5
N unique trials = 12
N replicates = 3
N total trials = 15

«xxxxxxxxxxxx» Effects for response 'Cr'

EFFECTS RESLTN SIG TERM

0.01214		0	CONSTANT
0.00049	0.00613	1	pH
-0.02901	***	2	logferrate
0.00246	0.00889	3	alum
-0.00036	0.00604	4	polymer

Residual SD = 0.003786
Replicate SD = 0.000000

N terms = 5
N unique trials = 12

N replicates = 3
N total trials = 15

«xxxxxxxxxxxx» Effects for response 'Fe'

LACK-OF-FIT

EFFECTS RESLTN SIG TERM

8.266		0	CONSTANT
0.976	4.140	1	pH
-18.909	***	2	logferrate
0.456	4.056	3	alum
0.342	3.530	4	polymer

Residual SD = 2.122410

Replicate SD = 0.090185

N terms = 5
N unique trials = 12
N replicates = 3
N total trials = 15

«xxxxxxxxxxxx» Effects for response 'Se'

EFFECTS RESLTN SIG TERM

0.04948		0	CONSTANT
0.00336	0.00781	1	pH
0.00636	0.01480	2	logferrate
-0.00099	0.00605	3	alum
-0.00143	0.00592	4	polymer

Residual SD = 0.002985

Replicate SD = 0.002082

N terms = 5
N unique trials = 12
N replicates = 3

N total trials = 15

«xxxxxxxxxxxxxx» Effects for response 'Ag'

EFFECTS RESLTN SIG TERM

0.01334		0	CONSTANT
0.00308	0.00910		1 pH
-0.02690	***	2	logferrate
0.00189	0.00873		3 alum
-0.00302	0.00907		4 polymer

Residual SD = 0.004031

Replicate SD = 0.002041

N terms = 5

N unique trials = 12

N replicates = 3

N total trials = 15

«xxxxxxxxxxxxxx» Effects for response 'V'

LACK-OF-FIT

EFFECTS RESLTN SIG TERM

0.01853		0	CONSTANT
0.00113	0.00633		1 pH
-0.04495	***	2	logferrate
0.00365	0.00956		3 alum
0.00069	0.00592		4 polymer

Residual SD = 0.003485

Replicate SD = 0.000408

N terms = 5

N unique trials = 12

N replicates = 3

N total trials = 15

PROJECT NAME: RF3.ECP

Created: Thu Oct 27 14:02:37 1994

«xxxxxxxxxxxx» Coefficients for response 'Am'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
--------------	----	---	-----------	------

0.332844			0	CONSTANT
-0.00477232	0.0165708	0.7792-	0.943	1 pH
-0.177047	0.0250332	0.0000	0.847	2 logferrate
0.000793209	0.00147026	0.6013-	0.841	3 alum
-0.00197069	0.0130205	0.8827-	0.866	4 polymer

N trials = 15

N terms = 5

Residual SD = 0.096570, Lack-Of-Fit P=0.0373 *

Residual DF = 10

Residual SD used for tests

Replicate SD = 0.034157

Replicate DF = 3

R Squared = 0.872, P=0.0002 ***

Adj R Squared = 0.821

Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

Maximum studentized residual = 7.858 P=0.0042 **

- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'Pu'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
--------------	----	---	-----------	------

3.06778			0	CONSTANT
-0.0540345	0.107661	0.6266-	0.943	1 pH
-1.51764	0.162642	0.0000	0.847	2 logferrate
0.003753	0.00955237	0.7026-	0.841	3 alum

0.0200388 0.0845945 0.8175- 0.866 4 polymer

N trials = 15

N terms = 5

Residual SD = 0.627420, Lack-Of-Fit P=0.0004 ***

Residual DF = 10

Residual SD used for tests

Replicate SD = 0.046726

Replicate DF = 3

R Squared = 0.923, P=0.0000 ***

Adj R Squared = 0.892

Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

Maximum studentized residual = 9.825 P=0.0000 ***

- This term may be eliminated

«xxxxxxxxxxxxxxxx» Coefficients for response 'U'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
--------------	----	---	-----------	------

0.0179644			0	CONSTANT
-----------	--	--	---	----------

-0.0105585	0.000952577	0.0000	0.943	1 pH
------------	-------------	--------	-------	------

-0.000472097	0.00143904	0.7496-	0.847	2 logferrate
--------------	------------	---------	-------	--------------

1.23131e-005	8.45186e-005	0.8871-	0.841	3 alum
--------------	--------------	---------	-------	--------

-5.29126e-005	0.000748485	0.9450-	0.866	4 polymer
---------------	-------------	---------	-------	-----------

N trials = 15

N terms = 5

Residual SD = 0.005551, Lack-Of-Fit P=0.0007 ***

Residual DF = 10

Residual SD used for tests

Replicate SD = 0.000524

Replicate DF = 3

R Squared = 0.934, P=0.0000 ***

Adj R Squared = 0.907

Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

Maximum studentized residual = 9.843 P=0.0000 ***
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'Al'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
7.99939			0	CONSTANT
0.0237025	0.275051	0.9330-	0.943	1 pH
-3.8227	0.415515	0.0000	0.847	2 logferrate
0.0378288	0.0244042	0.1522	0.841	3 alum
0.0784541	0.216121	0.7242-	0.866	4 polymer

N trials = 15
N terms = 5

Residual SD = 1.602920, Lack-Of-Fit P=0.0018 **
Residual DF = 10
Residual SD used for tests

Replicate SD = 0.204124
Replicate DF = 3

R Squared = 0.910, P=0.0000 ***
Adj R Squared = 0.874
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
Maximum studentized residual = 9.171 P=0.0001 ***
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'Ba'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.0960052			0	CONSTANT
-0.0237139	0.00273057	0.0000	0.943	1 pH
-0.033352	0.00412502	0.0000	0.847	2 logferrate
-0.000161626	0.000242273	0.5198-	0.841	3 alum
0.000370484	0.00214554	0.8664-	0.866	4 polymer

N trials = 15
N terms = 5

Residual SD = 0.015913
Residual DF = 10
Residual SD used for tests

Replicate SD = 0.000000
Replicate DF = 3

R Squared = 0.960, P=0.0000 ***
Adj R Squared = 0.944
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
- This term may be eliminated

«xxxxxxxxxxxxxx» Coefficients for response 'Cr'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.0121402			0	CONSTANT
0.000125132	0.000649636	0.8511-	0.943	1 pH
-0.00592617	0.000981394	0.0001	0.847	2 logferrate
4.92949e-005	5.76398e-005	0.4124-	0.841	3 alum
-7.12924e-005	0.00051045	0.8917-	0.866	4 polymer

N trials = 15
N terms = 5

Residual SD = 0.003786
Residual DF = 10
Residual SD used for tests

Replicate SD = 0.000000
Replicate DF = 3

R Squared = 0.820, P=0.0010 ***
Adj R Squared = 0.748
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
Maximum studentized residual = 8.151 P=0.0021 **
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'Fe'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
8.26555			0	CONSTANT
0.250179	0.364192	0.5077-	0.943	1 pH
-3.86291	0.550179	0.0000	0.847	2 logferrate
0.00912676	0.0323134	0.7834-	0.841	3 alum
0.0683267	0.286163	0.8161-	0.866	4 polymer

N trials = 15

N terms = 5

Residual SD = 2.122410, Lack-Of-Fit P=0.0001 ***

Residual DF = 10

Residual SD used for tests

Replicate SD = 0.090185

Replicate DF = 3

R Squared = 0.860, P=0.0003 ***

Adj R Squared = 0.804

Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

Maximum studentized residual = 9.409 P=0.0000 ***

- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'Se'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.0494791			0	CONSTANT
0.000861708	0.000512243	0.1234	0.943	1 pH
0.00129838	0.000773836	0.1243	0.847	2 logferrate
-1.97509e-005	4.54494e-005	0.6731-	0.841	3 alum
-0.000286753	0.000402493	0.4925-	0.866	4 polymer

N trials = 15

N terms = 5

Residual SD = 0.002985
Residual DF = 10
Residual SD used for tests

Replicate SD = 0.002082
Replicate DF = 3

R Squared = 0.439, P=0.1772
Adj R Squared = 0.215
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
- This term may be eliminated

«xxxxxxxxxxxxxx» Coefficients for response 'Ag'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.0133403			0	CONSTANT
0.000790988	0.000691696	0.2794-	0.943	1 pH
-0.00549468	0.00104493	0.0004	0.847	2 logferrate
3.78901e-005	6.13715e-005	0.5508-	0.841	3 alum
-0.000603806	0.000543498	0.2926-	0.866	4 polymer

N trials = 15
N terms = 5

Residual SD = 0.004031
Residual DF = 10
Residual SD used for tests

Replicate SD = 0.002041
Replicate DF = 3

R Squared = 0.793, P=0.0019 **
Adj R Squared = 0.710
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
Maximum studentized residual = 6.703 P=0.0308 *
- This term may be eliminated

«xxxxxxxxxxxxxx» Coefficients for response 'V'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.0185256			0	CONSTANT
0.000289925	0.000598041	0.6383-	0.943	1 pH
-0.00918185	0.000903451	0.0000	0.847	2 logferrate
7.29692e-005	5.3062e-005	0.1991	0.841	3 alum
0.000137551	0.000469909	0.7757-	0.866	4 polymer

N trials = 15

N terms = 5

Residual SD = 0.003485, Lack-Of-Fit P=0.0014 **

Residual DF = 10

Residual SD used for tests

Replicate SD = 0.000408

Replicate DF = 3

R Squared = 0.925, P=0.0000 ***

Adj R Squared = 0.895

Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

Maximum studentized residual = 7.424 P=0.0098 **

- This term may be eliminated

PROJECT NAME: RF3.ECP

Created: Thu Oct 27 14:02:52 1994

«xxxxxxxxxxxxxx» ANOVA Table for response 'Am'

LACK-OF-FIT

Mean Squares DF P

0.000773493	1	0.7792	pH
0.466476	1	0.0000	logferrate
0.00271437	1	0.6013	alum
0.000213633	1	0.8827	polymer
0.00932576	10		ERROR
0.00116667	3		REPLICATE ERROR

«xxxxxxxxxxxxxx» ANOVA Table for response 'Pu'

LACK-OF-FIT

Mean Squares DF P

0.0991608	1	0.6266	pH
34.276	1	0.0000	logferrate
0.0607647	1	0.7026	alum
0.022089	1	0.8175	polymer
0.393655	10		ERROR
0.00218333	3		REPLICATE ERROR

«xxxxxxxxxxxxxx» ANOVA Table for response 'U'

LACK-OF-FIT

Mean Squares DF P

0.00378621	1	0.0000	pH
3.31676e-006	1	0.7496	logferrate
6.54074e-007	1	0.8871	alum
1.5401e-007	1	0.9450	polymer

3.08176e-005 10 ERROR
2.74999e-007 3 REPLICATE ERROR

«xxxxxxxxxxxxxx» ANOVA Table for response 'Al'

LACK-OF-FIT

Mean Squares DF P

0.0190804	1	0.9330	pH
217.466	1	0.0000	logferrate
6.17359	1	0.1522	alum
0.338581	1	0.7242	polymer
2.56935	10		ERROR

0.0416667 3 REPLICATE ERROR

«xxxxxxxxxxxxxx» ANOVA Table for response 'Ba'

Mean Squares DF P

0.0190987	1	0.0000	pH
0.0165537	1	0.0000	logferrate
0.000112698	1	0.5198	alum
7.5504e-006	1	0.8664	polymer
0.000253223	10		ERROR

0 3 REPLICATE ERROR

«xxxxxxxxxxxxxx» ANOVA Table for response 'Cr'

Mean Squares DF P

5.31786e-007	1	0.8511	pH
0.000522636	1	0.0001	logferrate
1.04833e-005	1	0.4124	alum
2.79588e-007	1	0.8917	polymer
1.4333e-005	10		ERROR

0 3 REPLICATE ERROR

«xxxxxxxxxxxxxx» ANOVA Table for response 'Fe'

LACK-OF-FIT

Mean Squares DF P

2.12569	1	0.5077	pH
222.065	1	0.0000	logferrate
0.359358	1	0.7834	alum
0.25681	1	0.8161	polymer
4.50463	10		ERROR

0.00813333 3 REPLICATE ERROR

«xxxxxxxxxxxxxx» ANOVA Table for response 'Se'

Mean Squares DF P

2.52184e-005	1	0.1234	pH
2.50872e-005	1	0.1243	logferrate
1.68294e-006	1	0.6731	alum
4.52322e-006	1	0.4925	polymer
8.91147e-006	10		ERROR

4.33333e-006 3 REPLICATE ERROR

«xxxxxxxxxxxxxx» ANOVA Table for response 'Ag'

Mean Squares DF P

2.1249e-005	1	0.2794	pH
0.000449299	1	0.0004	logferrate
6.19362e-006	1	0.5508	alum
2.00552e-005	1	0.2926	polymer
1.6249e-005	10		ERROR

4.16667e-006 3 REPLICATE ERROR

«xxxxxxxxxxxxxx» ANOVA Table for response 'V'

LACK-OF-FIT

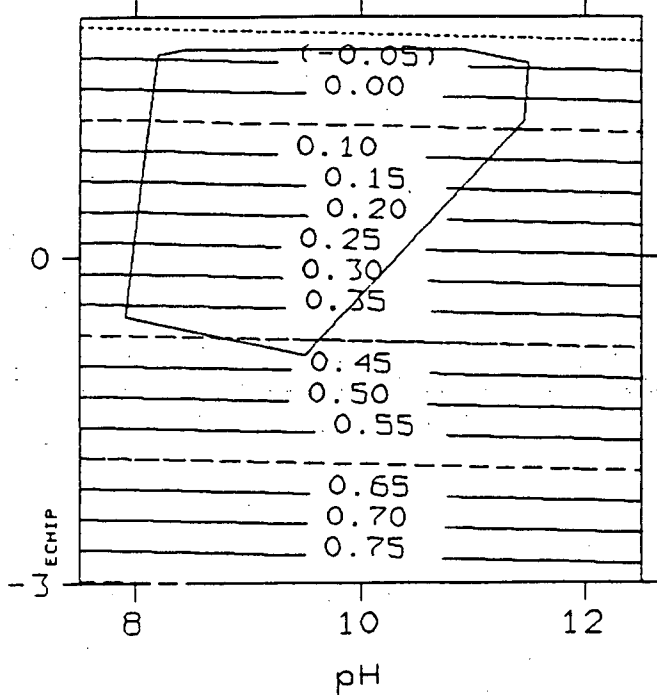
Mean Squares DF P

2.85475e-006	1	0.6383	pH
0.00125462	1	0.0000	logferrate
2.29706e-005	1	0.1991	alum
1.04078e-006	1	0.7757	polymer
1.21468e-005	10		ERROR
1.66667e-007	3		REPLICATE ERROR

Am

Lack Of Fit

logferrate



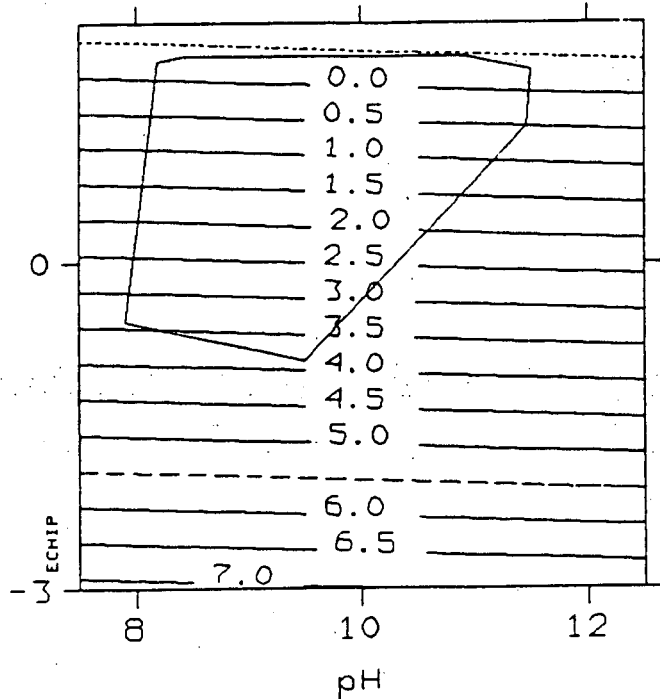
alum = 25.000000

polymer = 2.500000

Pu

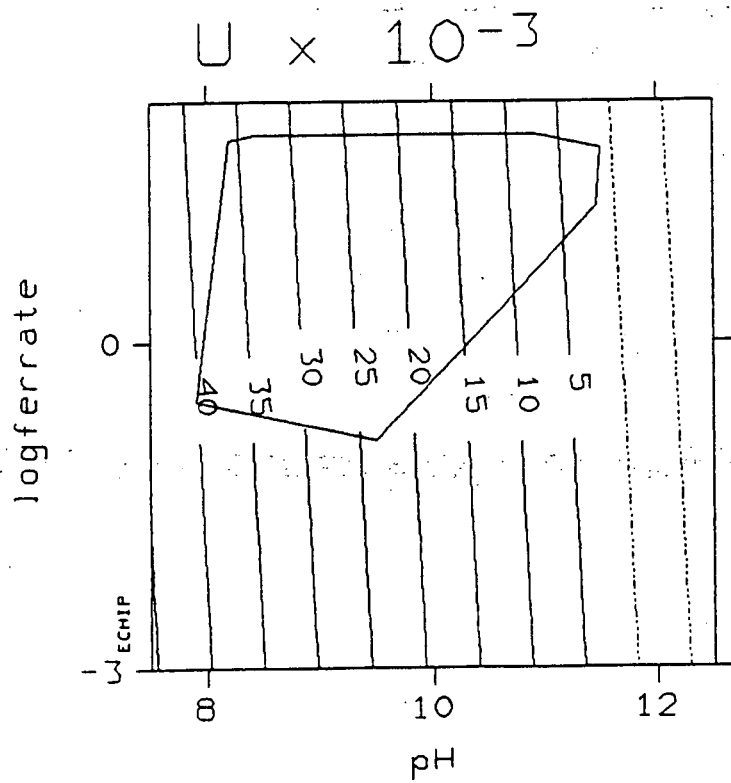
Lack Of Fit

logferrate



alum = 25.000000

polymer = 2.500000



Lack Of Fit

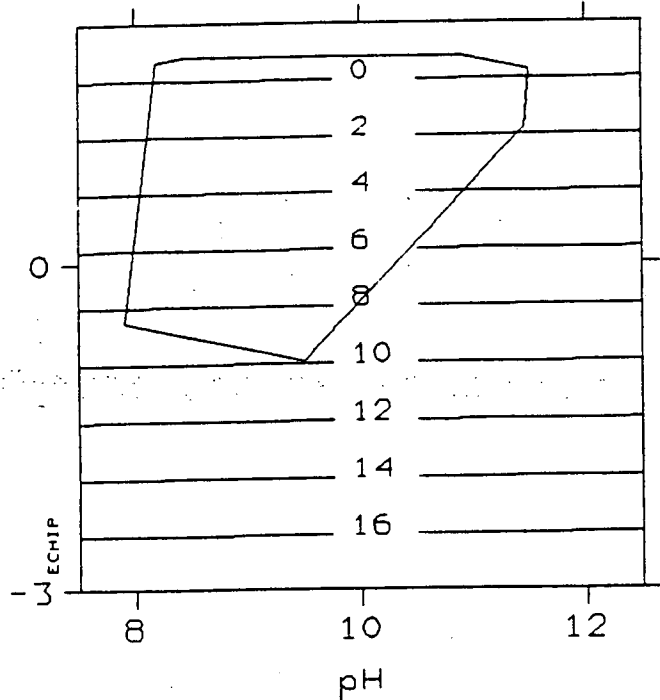
alum = 25.000000

polymer = 2.500000

A1

Lack Of Fit

logferrate

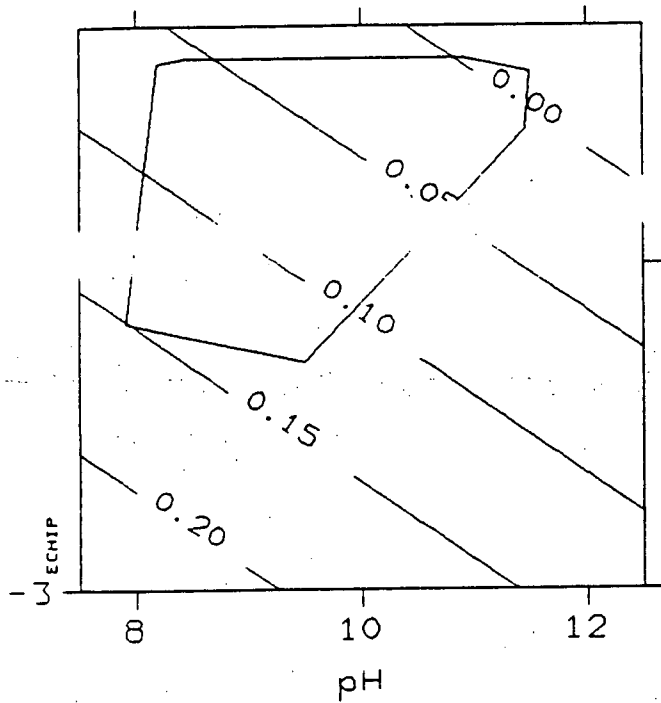


alum = 25.000000

polymer = 2.500000

Ba

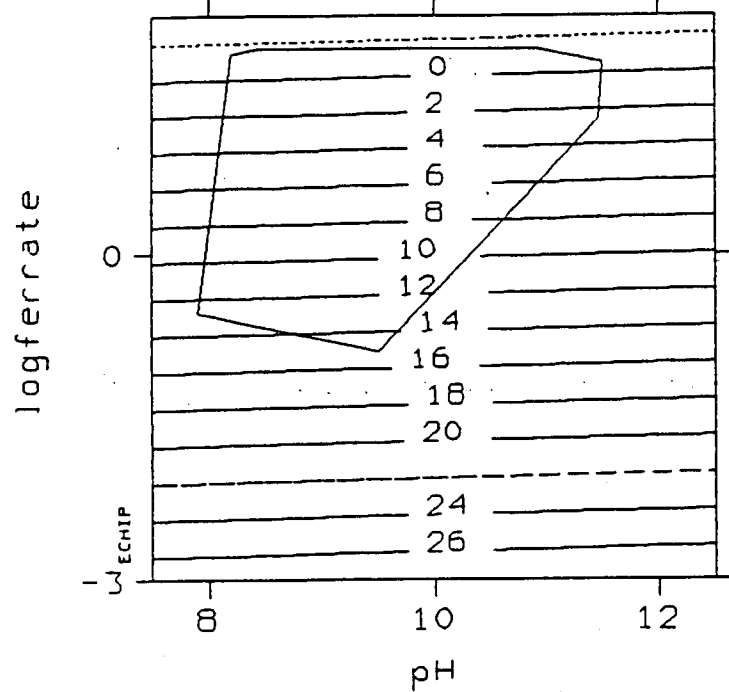
logferite



1.000000

polymer = 2.500000

Cr $\times 10^{-3}$

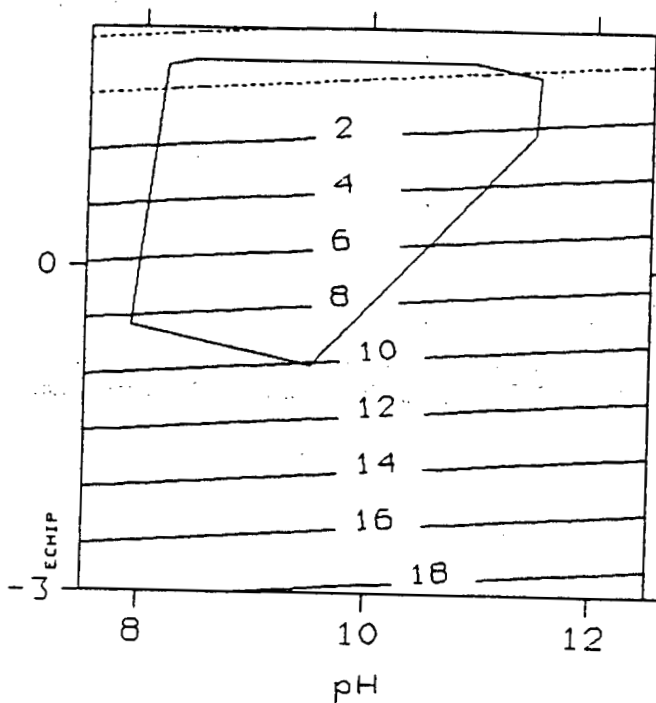


alum = 25.000000

polymer = 2.500000

Fe

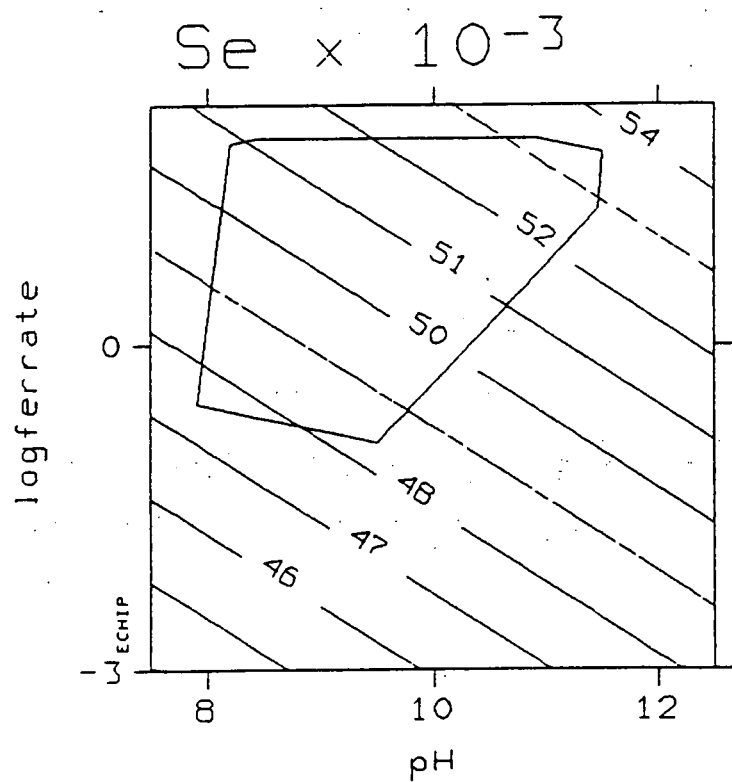
logferrate



Lack Of Fit

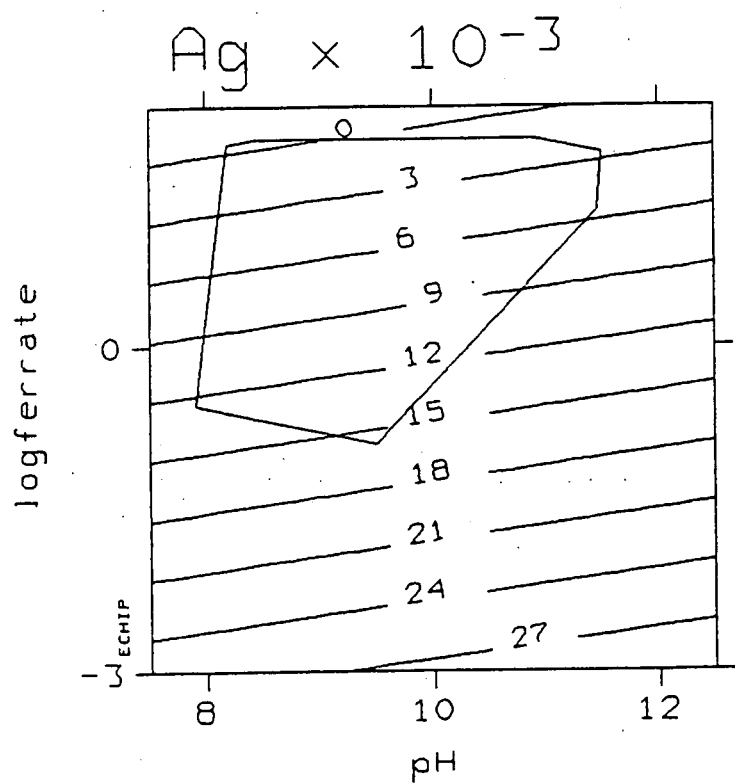
alum = 25.000000

polymer = 2.500000



alum = 25.000000

polymer = 2.500000



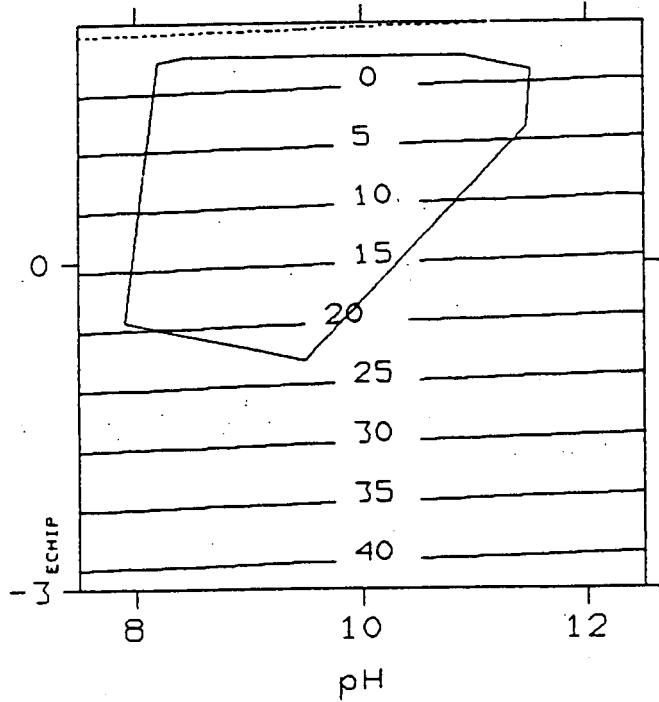
alum = 25.000000

polymer = 2.500000

$V \times 10^{-3}$

Lack Of Fit

log ferrate



alum = 25.000000

polymer = 2.500000

APPENDIX C

PHASE I MODIFIED TEST PLAN ECHIP OUTPUT

Created: Thu Nov 03 09:36:03 1994

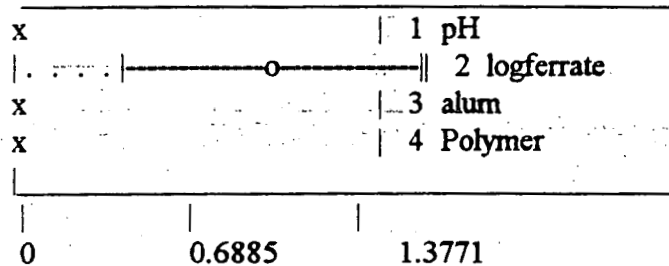
[illegible]

- 1 pH
2 logferrate
3 alum
4 Polymer

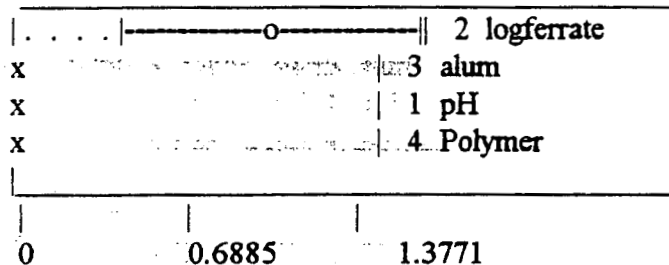
PROJECT NAME: ROCKYFLA.ECP

Created: Thu Nov 03 09:35:54 1994

«xxxxxxxxxxxxxxxx» Effects graph for response 'Am'

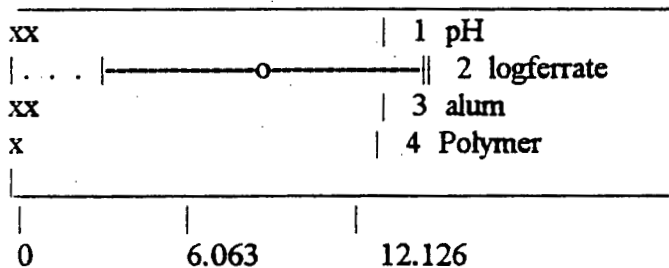


Pareto effects graph for response 'Am'



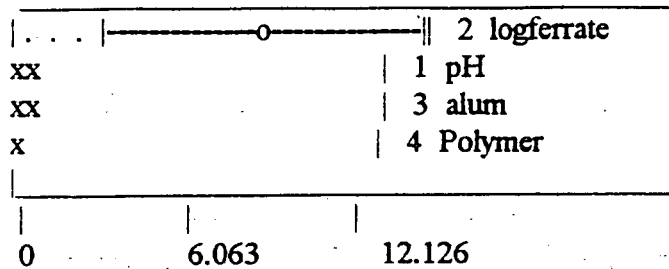
«xxxxxxxxxxxxxxxx» Effects graph for response 'Pu'

LACK-OF-FIT

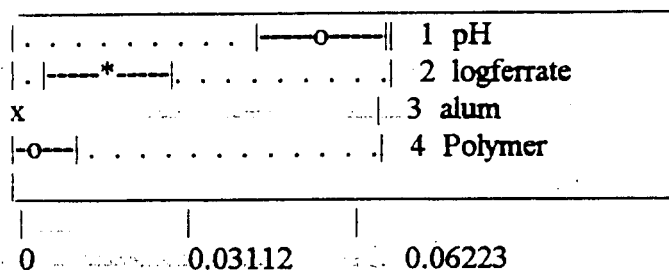


****Pareto effects graph for response 'Pu'****

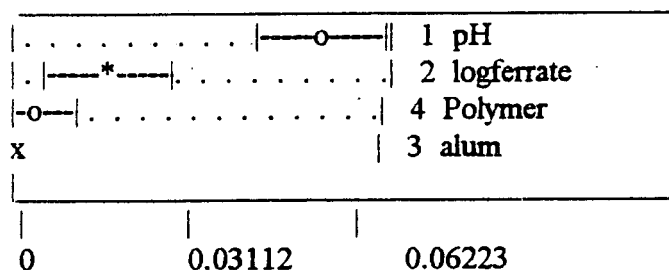
LACK-OF-FIT



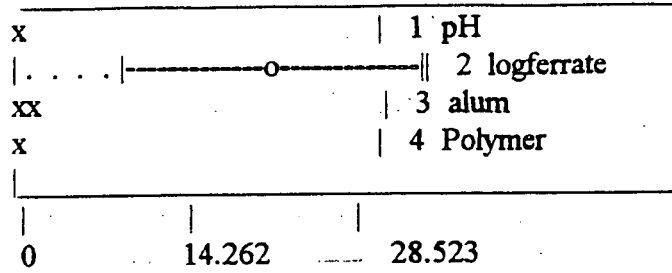
«xxxxxxxxxxxxxxxx» Effects graph for response 'U'



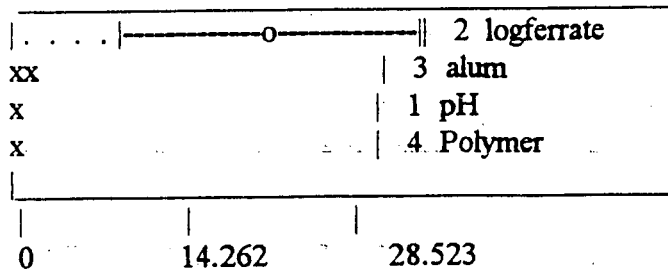
****Pareto effects graph for response 'U'****



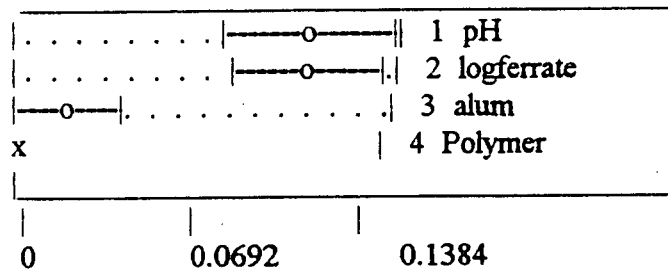
«xxxxxxxxxxxxxxxx» Effects graph for response 'Al'



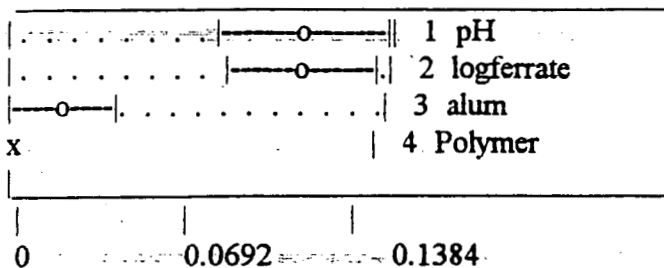
Pareto effects graph for response 'Al'



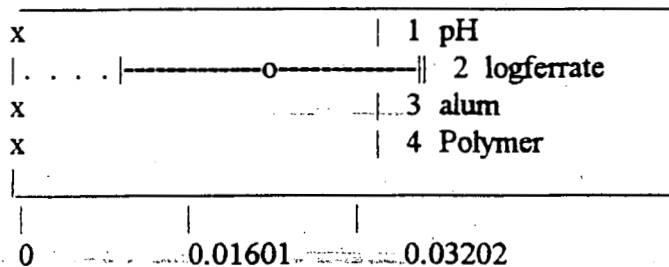
«xxxxxxxxxxxxxxxx» Effects graph for response 'Ba'



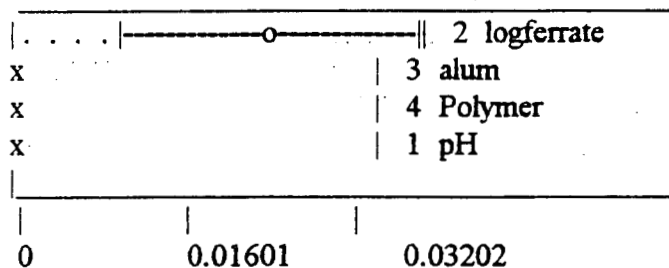
****Pareto effects graph for response 'Ba'****



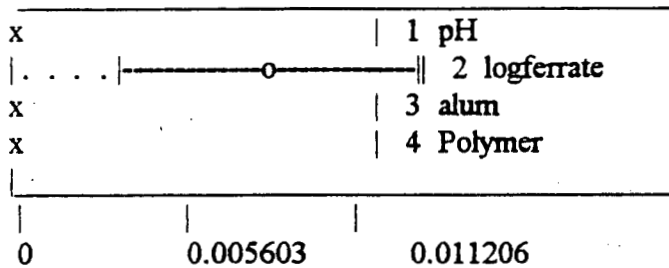
«xxxxxxxxxxxx» Effects graph for response 'Cr'



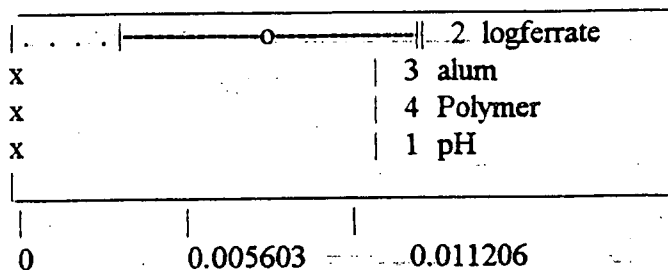
****Pareto effects graph for response 'Cr'****



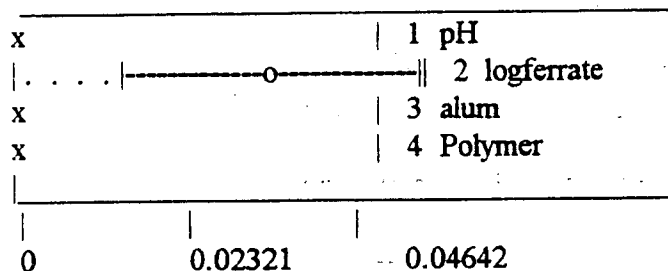
«xxxxxxxxxxxx» Effects graph for response 'Co'



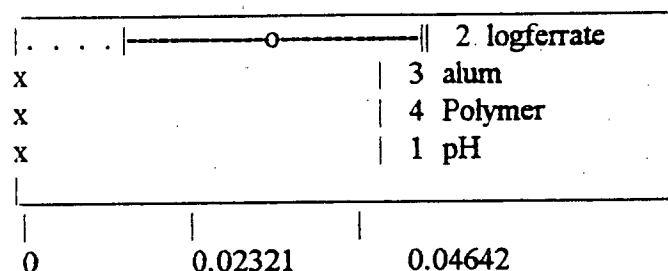
****Pareto effects graph for response 'Co'****



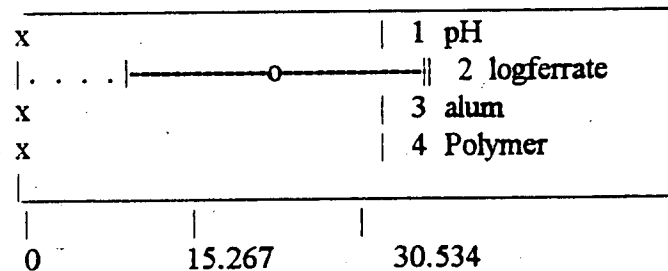
«xxxxxxxxxxxxxxxx» Effects graph for response 'Cu'



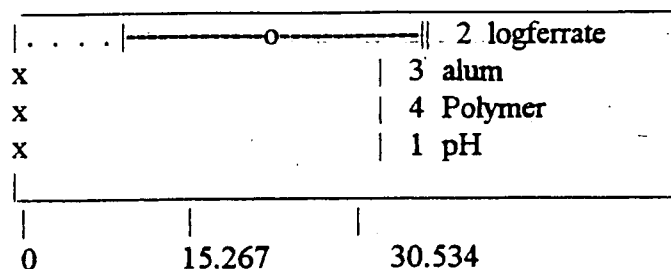
****Pareto effects graph for response 'Cu'****



«xxxxxxxxxxxxxxxx» Effects graph for response 'Fe'

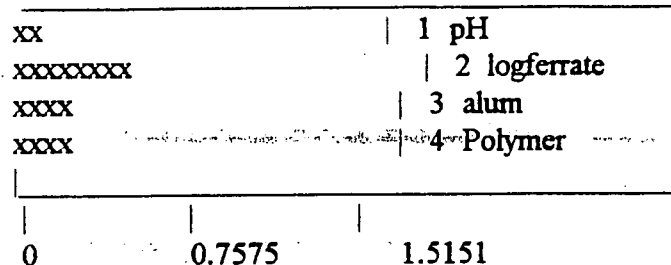


****Pareto effects graph for response 'Fe'****



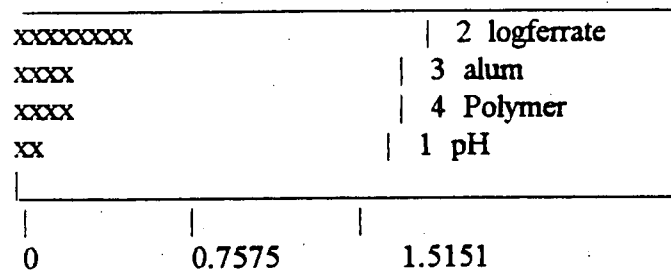
«xxxxxxxxxxxxxxxx» Effects graph for response 'Se'

LACK-OF-FIT

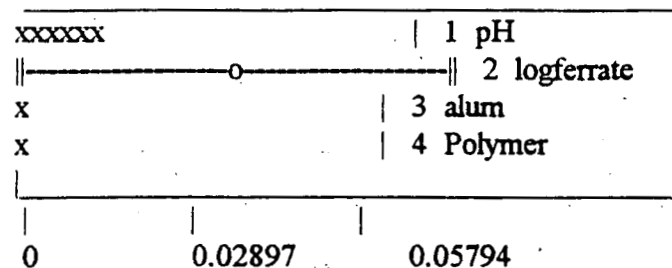


****Pareto effects graph for response 'Se'****

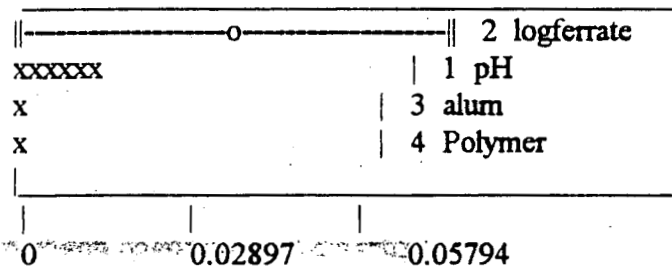
LACK-OF-FIT



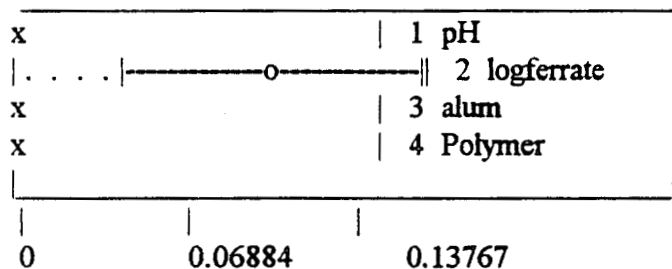
«xxxxxxxxxxxxxxxx» Effects graph for response 'Ag'



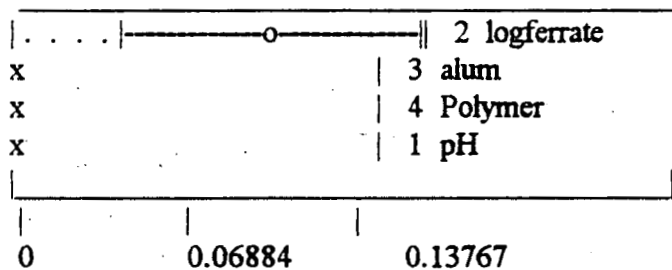
Pareto effects graph for response 'Ag'



«xxxxxxxxxxxxxxxx» Effects graph for response 'Zn'



Pareto effects graph for response 'Zn'



«xxxxxxxxxxxx» Effects for response 'Am'

EFFECTS RESLTN SIG TERM

0.0025		0	CONSTANT
0.0070	0.5022	1	pH
-0.8970	**	2	logferrate
-0.0182	0.3385	3	alum
-0.0001	0.2859	4	Polymer

Residual SD = 0.091206
Replicate SD = 0.021213

N terms = 5
N unique trials = 7
N replicates = 1
N total trials = 8

«xxxxxxxxxxxx» Effects for response 'Pu'

LACK-OF-FIT

EFFECTS RESLTN SIG TERM

0.116		0	CONSTANT
-0.417	4.939	1	pH
-7.742	*	2	logferrate
0.381	3.307	3	alum
0.138	2.748	4	Polymer

Residual SD = 0.832848
Replicate SD = 0.007071

N terms = 5

N replicates = 1
N total trials = 8

«xxxxxxxxxxxxxx» Effects for response 'U'

EFFECTS RESLTN SIG TERM

0.01970		0	CONSTANT
-0.05295	***	1	pH
0.01408	*	2	logferrate
0.00115	0.00716	3	alum
-0.00305	0.00841	4	Polymer

Residual SD = 0.001709
Replicate SD = 0.000707

N terms = 5
N unique trials = 7
N replicates = 1
N total trials = 8

«xxxxxxxxxxxxxx» Effects for response 'Al'

EFFECTS RESLTN SIG TERM

0.514		0	CONSTANT
-0.652	10.538	1	pH
-18.939	**	2	logferrate
1.210	7.605	3	alum
0.543	6.249	4	Polymer

Residual SD = 1.820774
Replicate SD = 0.000000

N terms = 5
N unique trials = 7
N replicates = 1

«xxxxxxxxxxxxxx» Effects for response 'Ba'

EFFECTS RESLTN SIG TERM

0.0386		0	CONSTANT
-0.1131	***	1	pH
-0.1111	***	2	logferrate
-0.0157	0.0322	3	alum
-0.0026	0.0172	4	Polymer

Residual SD = 0.004670

Replicate SD = 0.000000

N terms = 5

N unique trials = 7

N replicates = 1

N total trials = 8

«xxxxxxxxxxxxxx» Effects for response 'Cr'

EFFECTS RESLTN SIG TERM

0.00019		0	CONSTANT
-0.00047	0.01159	1	pH
-0.02123	**	2	logferrate
0.00064	0.00784	3	alum
0.00062	0.00705	4	Polymer

Residual SD = 0.002049

Replicate SD = 0.000000

N terms = 5

N unique trials = 7

N replicates = 1

N total trials = 8

«xxxxxxxxxxxxxx» Effects for response 'Co'

EFFECTS RESLTN SIG TERM

0.000067		0	CONSTANT
-0.000164	0.004058		1 pH
-0.007431		**	2 logferrate
0.000225	0.002744		3 alum
0.000219	0.002466		4 Polymer

Residual SD = 0.000717

Replicate SD = 0.000000

N terms = 5

N unique trials = 7

N replicates = 1

N total trials = 8

«xxxxxxxxxxxxxx» Effects for response 'Cu'

EFFECTS RESLTN SIG TERM

0.00028		0	CONSTANT
-0.00068	0.01681		1 pH
-0.03079		**	2 logferrate
0.00093	0.01137		3 alum
0.00091	0.01022		4 Polymer

Residual SD = 0.002971

Replicate SD = 0.000000

N terms = 5

N unique trials = 7

N replicates = 1

N total trials = 8

«xxxxxxxxxxxxxx» Effects for response 'Fe'

EFFECTS RESLTN SIG TERM

0.261		0	CONSTANT
-0.292	10.957	1	pH
-20.194	**	2	logferrate
0.604	7.503	3	alum
0.602	6.757	4	Polymer

Residual SD = 1.964244

Replicate SD = 0.000000

N terms = 5

N unique trials = 7

N replicates = 1

N total trials = 8

«xxxxxxxxxxxx» Effects for response 'Se'

LACK-OF-FIT

EFFECTS RESLTN SIG TERM

0.1132		0	CONSTANT
-0.0717	1.3587	1	pH
0.2674	1.5151	2	logferrate
-0.1506	0.9831	3	alum
-0.1488	0.8916	4	Polymer

Residual SD = 0.237037

Replicate SD = 0.002828

N terms = 5

N unique trials = 7

N replicates = 1

N total trials = 8

«xxxxxx» Effects for response 'Ag'

EFFECTS RESLTN SIG TERM

0.00421		0	CONSTANT
0.00762	0.03636	1	pH
-0.03007	*	2	logferrate
-0.00135	0.01994	3	alum
-0.00022	0.01681	4	Polymer

Residual SD = 0.005294

Replicate SD = 0.000000

N terms = 5

N unique trials = 7

N replicates = 1

N total trials = 8

«xxxxxxxxxxxxxx» Effects for response 'Zn'

EFFECTS RESLTN SIG TERM

0.00083		0	CONSTANT
-0.00202	0.04985	1	pH
-0.09130	**	2	logferrate
0.00277	0.03371	3	alum
0.00268	0.03029	4	Polymer

Residual SD = 0.008810

Replicate SD = 0.000000

N terms = 5

N unique trials = 7

N replicates = 1

N total trials = 8

PROJECT NAME: ROCKYFLA.ECP

Created: Thu Nov 03 09:35:42 1994

«xxxxxxxxxxxxxxxx» Coefficients for response 'Am'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.00247295			0	CONSTANT
0.00302501	0.0676545	0.9671-	0.803	1 pH
-0.183251	0.0308181	0.0095	0.679	2 logferrate
-0.000363665	0.0020131	0.8682-	0.802	3 alum
-2.14618e-005	0.0179623	0.9991-	0.835	4 Polymer

N trials = 8

N terms = 5

Residual SD = 0.091206

Residual DF = 3

Residual SD used for tests

Replicate SD = 0.021213

Replicate DF = 1

R Squared = 0.963, P=0.0174 *

Adj R Squared = 0.914

Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

- This term may be eliminated

«xxxxxxxxxxxxxxxx» Coefficients for response 'Pu'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.115677			0	CONSTANT
-0.181463	0.617791	0.7881-	0.803	1 pH
-1.58158	0.281417	0.0111	0.679	2 logferrate
0.00762947	0.0183827	0.7060-	0.802	3 alum
0.0276479	0.164024	0.8769-	0.835	4 Polymer

N trials = 8
N terms = 5

Residual SD = 0.832848, Lack-Of-Fit P=0.0316 *
Residual DF = 3
Residual SD used for tests

Replicate SD = 0.007071
Replicate DF = 1

R Squared = 0.957, P=0.0220 *
Adj R Squared = 0.899
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
Maximum studentized residual = 2.996 P=0.0048 **
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'U'

Centered continuous variables

COEFFICIENTS SD P CONDITION TERM

0.0197023				0 CONSTANT
-0.0230218	0.0012679	0.0004	0.803	1 pH
0.00287712	0.000577554	0.0155	0.679	2 logferrate
2.3051e-005	3.7727e-005	0.5844	0.802	3 alum
-0.000610998	0.000336628	0.1671	0.835	4 Polymer

N trials = 8
N terms = 5

Residual SD = 0.001709
Residual DF = 3
Residual SD used for tests

Replicate SD = 0.000707
Replicate DF = 1

R Squared = 0.992, P=0.0018 **
Adj R Squared = 0.981
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'Al'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
--------------	----	---	-----------	------

0.513518			0	CONSTANT
----------	--	--	---	----------

-0.283369	1.35062	0.8473	0.803	1 pH
-----------	---------	--------	-------	------

-3.86907	0.615234	0.0081	0.679	2 logferrate
----------	----------	--------	-------	--------------

0.0242024	0.0401883	0.5895	0.802	3 alum
-----------	-----------	--------	-------	--------

0.108699	0.35859	0.7816	0.835	4 Polymer
----------	---------	--------	-------	-----------

N trials = 8

N terms = 5

Residual SD = 1.820774

Residual DF = 3

Residual SD used for tests

Replicate SD = 0.000000

Replicate DF = 1

R Squared = 0.963, P=0.0172 *

Adj R Squared = 0.914

Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

Maximum studentized residual = 3.000 P=0.0000 ***

- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'Ba'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
--------------	----	---	-----------	------

0.0386266			0	CONSTANT
-----------	--	--	---	----------

-0.0491524	0.00346426	0.0008	0.803	1 pH
------------	------------	--------	-------	------

-0.0226995	0.00157805	0.0007	0.679	2 logferrate
------------	------------	--------	-------	--------------

-0.000314993	0.000103081	0.0552	0.802	3 alum
--------------	-------------	--------	-------	--------

-0.000520995	0.000919765	0.6107	0.835	4 Polymer
--------------	-------------	--------	-------	-----------

N trials = 8

N terms = 5

Residual SD = 0.004670

Residual DF = 3

Residual SD used for tests

Replicate SD = 0.000000

Replicate DF = 1

R Squared = 0.998, P=0.0003 ***

Adj R Squared = 0.995

Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

Maximum studentized residual = 2.999 P=0.0013 **

- This term may be eliminated

«xxxxxxxxxxxxxxxx» Coefficients for response 'Cr'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
--------------	----	---	-----------	------

0.000192196			0	CONSTANT
-------------	--	--	---	----------

-0.00020391	0.00151984	0.9018-	0.803	1 pH
-------------	------------	---------	-------	------

-0.00433739	0.000692319	0.0082	0.679	2 logferrate
-------------	-------------	--------	-------	--------------

1.28812e-005	4.52237e-005	0.7943-	0.802	3 alum
--------------	--------------	---------	-------	--------

0.000124873	0.000403519	0.7772-	0.835	4 Polymer
-------------	-------------	---------	-------	-----------

N trials = 8

N terms = 5

Residual SD = 0.002049

Residual DF = 3

Residual SD used for tests

Replicate SD = 0.000000

Replicate DF = 1

R Squared = 0.964, P=0.0167 *

Adj R Squared = 0.916

Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

Maximum studentized residual = 3.000 P=0.0000 ***

- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'Co'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
--------------	----	---	-----------	------

6.72685e-005			0	CONSTANT
-7.13685e-005	0.000531943	0.9018-	0.803	1 pH
-0.00151809	0.000242311	0.0082	0.679	2 logferrate
4.50844e-006	1.58283e-005	0.7943-	0.802	3 alum
4.37054e-005	0.000141232	0.7772-	0.835	4 Polymer

N trials = 8
N terms = 5

Residual SD = 0.000717
Residual DF = 3
Residual SD used for tests

Replicate SD = 0.000000
Replicate DF = 1

R Squared = 0.964, P=0.0167 *
Adj R Squared = 0.916
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
Maximum studentized residual = 3.000 P=0.0000 ***
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'Cu'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
--------------	----	---	-----------	------

0.000278684			0	CONSTANT
-0.000295669	0.00220377	0.9018-	0.803	1 pH
-0.00628922	0.00100386	0.0082	0.679	2 logferrate
1.86778e-005	6.55743e-005	0.7943-	0.802	3 alum
0.000181065	0.000585102	0.7772-	0.835	4 Polymer

N trials = 8
N terms = 5

Residual SD = 0.002971
Residual DF = 3
Residual SD used for tests

Replicate SD = 0.000000
Replicate DF = 1

R Squared = 0.964, P=0.0167 *
Adj R Squared = 0.916
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
Maximum studentized residual = 3.000 P=0.0000 ***
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'Fe'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
--------------	----	---	-----------	------

0.261247			0	CONSTANT
----------	--	--	---	----------

-0.127093	1.45704	0.9360	0.803	1 pH
-----------	---------	--------	-------	------

-4.12549	0.663712	0.0084	0.679	2 logferrate
----------	----------	--------	-------	--------------

0.012078	0.043355	0.7987	0.802	3 alum
----------	----------	--------	-------	--------

0.120344	0.386845	0.7761	0.835	4 Polymer
----------	----------	--------	-------	-----------

N trials = 8
N terms = 5

Residual SD = 1.964244
Residual DF = 3
Residual SD used for tests

Replicate SD = 0.000000
Replicate DF = 1

R Squared = 0.963, P=0.0173 *
Adj R Squared = 0.914
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000
Maximum studentized residual = 3.000 P=0.0000 ***
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'Se'

Centered continuous variables

COEFFICIENTS SD P CONDITION TERM

0.113216			0	CONSTANT
-0.0311594	0.175829	0.8706-	0.803	1 pH
0.0546185	0.080094	0.5442-	0.679	2 logferrate
-0.00301146	0.0052319	0.6052-	0.802	3 alum
-0.0297616	0.0466829	0.5691-	0.835	4 Polymer

N trials = 8

N terms = 5

Residual SD = 0.237037, Lack-Of-Fit P=0.0316 *

Residual DF = 3

Residual SD used for tests

Replicate SD = 0.002828

Replicate DF = 1

R Squared = 0.262, P=0.8834

Adj R Squared = 0.000

Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

Maximum studentized residual = 3.000 P=0.0002 ***

- This term may be eliminated

«xxxxxxxxxxxxxx» Coefficients for response 'Ag'

Centered continuous variables

COEFFICIENTS SD P CONDITION TERM

0.00420908			0	CONSTANT
0.00331102	0.00392701	0.4611-	0.803	1 pH
-0.00614331	0.00178884	0.0414	0.679	2 logferrate
-2.69518e-005	0.00011685	0.8324-	0.802	3 alum
-4.32029e-005	0.00104263	0.9696-	0.835	4 Polymer

N trials = 8

N terms = 5

Residual SD = 0.005294

Residual DF = 3

Residual SD used for tests

Replicate SD = 0.000000

Replicate DF = 1

R Squared = 0.881, P=0.0956

Adj R Squared = 0.722

Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

- This term may be eliminated

«xxxxxxxxxxxxxx» Coefficients for response 'Zn'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
--------------	----	---	-----------	------

0.000826442			0	CONSTANT
-------------	--	--	---	----------

-0.000876813	0.0065353	0.9018-	0.803	1 pH
--------------	-----------	---------	-------	------

-0.0186508	0.00297697	0.0082	0.679	2 logferrate
------------	------------	--------	-------	--------------

5.53893e-005	0.000194462	0.7943-	0.802-	3 alum
--------------	-------------	---------	--------	--------

0.000536952	0.00173513	0.7772-	0.835-	4 Polymer
-------------	------------	---------	--------	-----------

N trials = 8

N terms = 5

Residual SD = 0.008810

Residual DF = 3

Residual SD used for tests

Replicate SD = 0.000000

Replicate DF = 1

R Squared = 0.964, P=0.0167 *

Adj R Squared = 0.916

Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

Maximum studentized residual = 3.000 P=0.0000 ***

- This term may be eliminated

PROJECT NAME: ROCKYFLA.ECP

Created: Thu Nov 03 09:36:01 1994

«xxxxxxxxxxxxxx» ANOVA Table for response 'Am'

Mean Squares DF P

1.66303e-005	1	0.9671	pH
0.294119	1	0.0095	logferrate
0.000271465	1	0.8682	alum
1.18755e-008	1	0.9991	Polymer
0.00831845	3		ERROR

0.00045 1 REPLICATE ERROR

«xxxxxxxxxxxxxx» ANOVA Table for response 'Pu'

LACK-OF-FIT

Mean Squares DF P

0.0598446	1	0.7881	pH
21.9085	1	0.0111	logferrate
0.119481	1	0.7060	alum
0.0197079	1	0.8769	Polymer
0.693636	3		ERROR

5.00001e-005 1 REPLICATE ERROR

«xxxxxxxxxxxxxx» ANOVA Table for response 'U'

Mean Squares DF P

0.000963222	1	0.0004	pH
7.25014e-005	1	0.0155	logferrate
1.09066e-006	1	0.5844	alum
9.62489e-006	1	0.1671	Polymer
2.92158e-006	3		ERROR

4.99998e-007 1 REPLICATE ERROR

«xxxxxxxxxxxxxx» ANOVA Table for response 'Al'

Mean Squares DF P

0.145933 1 0.8473 pH
131.113 1 0.0081 logferrate
1.20235 1 0.5895 alum
0.304624 1 0.7816 Polymer
3.31522 3 ERROR

0 1 REPLICATE ERROR

«xxxxxxxxxxxxxx» ANOVA Table for response 'Ba'

Mean Squares DF P

0.00439075 1 0.0008 pH
0.00451297 1 0.0007 logferrate
0.000203664 1 0.0552 alum
6.99816e-006 1 0.6107 Polymer
2.18107e-005 3 ERROR

0 1 REPLICATE ERROR

«xxxxxxxxxxxxxx» ANOVA Table for response 'Cr'

Mean Squares DF P

7.55658e-008 1 0.9018 pH
0.000164774 1 0.0082 logferrate
3.40586e-007 1 0.7943 alum
4.02022e-007 1 0.7772 Polymer
4.19801e-006 3 ERROR

0 1 REPLICATE ERROR

«xxxxxxxxxxxxxx» ANOVA Table for response 'Co'

Mean Squares DF P

9.25681e-009	1	0.9018	pH
2.01848e-005	1	0.0082	logferrate
4.17218e-008	1	0.7943	alum
4.92477e-008	1	0.7772	Polymer
5.14256e-007	3		ERROR

0 1 REPLICATE ERROR

«xxxxxxxxxxxxxxxx» ANOVA Table for response 'Cu'

Mean Squares DF P

1.58877e-007	1	0.9018	pH
0.000346437	1	0.0082	logferrate
7.16083e-007	1	0.7943	alum
8.45251e-007	1	0.7772	Polymer
8.82631e-006	3		ERROR

0 1 REPLICATE ERROR

«xxxxxxxxxxxxxxxx» ANOVA Table for response 'Fe'

Mean Squares DF P

0.0293557	1	0.9360	pH
149.068	1	0.0084	logferrate
0.299435	1	0.7987	alum
0.37339	1	0.7761	Polymer
3.85825	3		ERROR

0 1 REPLICATE ERROR

«xxxxxxxxxxxxxxxx» ANOVA Table for response 'Se'

LACK-OF-FIT

Mean Squares DF P

0.00176452	1	0.8706	pH
0.0261283	1	0.5442	logferrate
0.0186151	1	0.6052	alum
0.0228365	1	0.5691	Polymer
0.0561864	3		ERROR

8e-006 1 REPLICATE ERROR

«xxxxxxxxxxxxxx» ANOVA Table for response 'Ag'

Mean Squares DF P

1.99238e-005	1	0.4611	pH
0.00033055	1	0.0414	logferrate
1.49103e-006	1	0.8324	alum
4.81218e-008	1	0.9696	Polymer
2.80268e-005	3		ERROR

0 1 REPLICATE ERROR

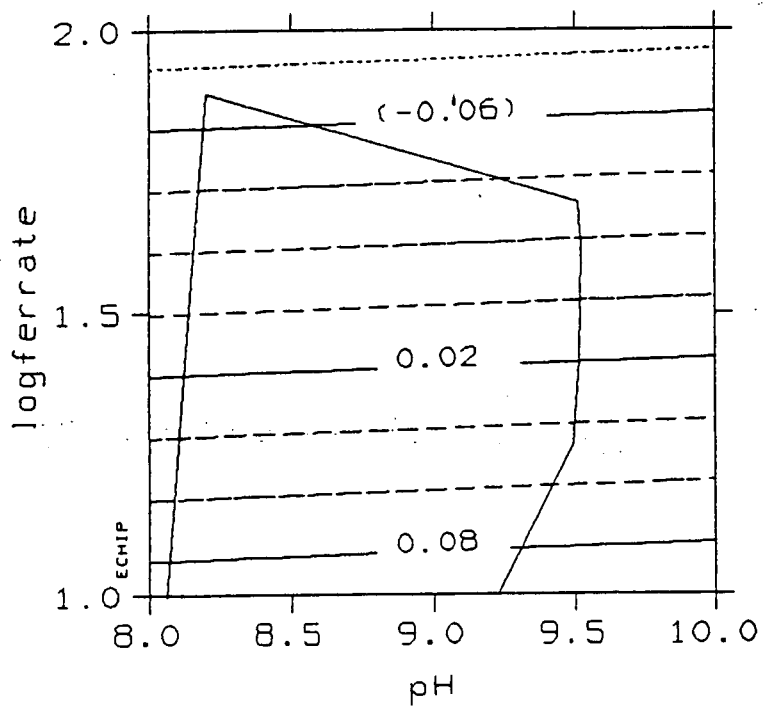
«xxxxxxxxxxxxxx» ANOVA Table for response 'Zn'

Mean Squares DF P

1.39721e-006	1	0.9018	pH
0.00304667	1	0.0082	logferrate
6.29744e-006	1	0.7943	alum
7.43339e-006	1	0.7772	Polymer
7.76212e-005	3		ERROR

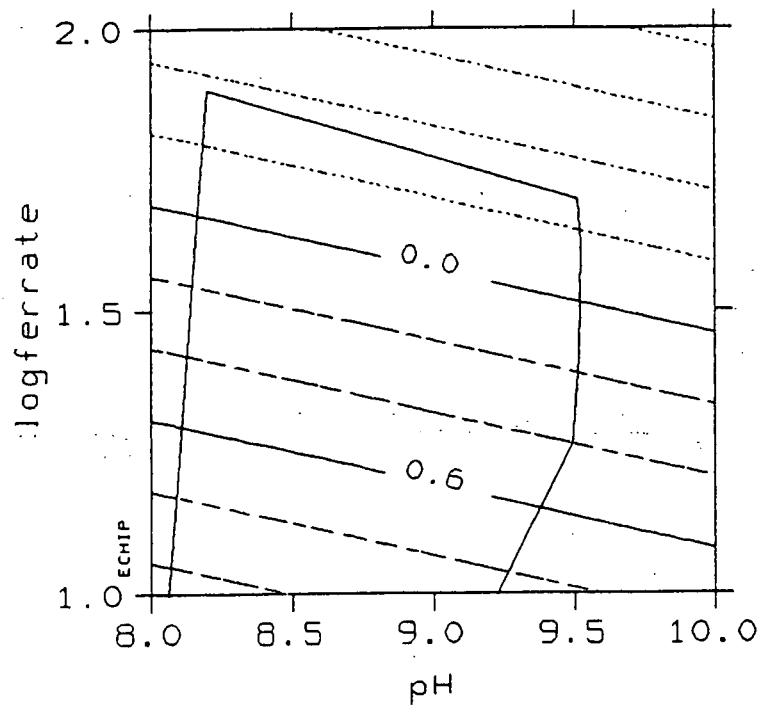
0 1 REPLICATE ERROR

Am



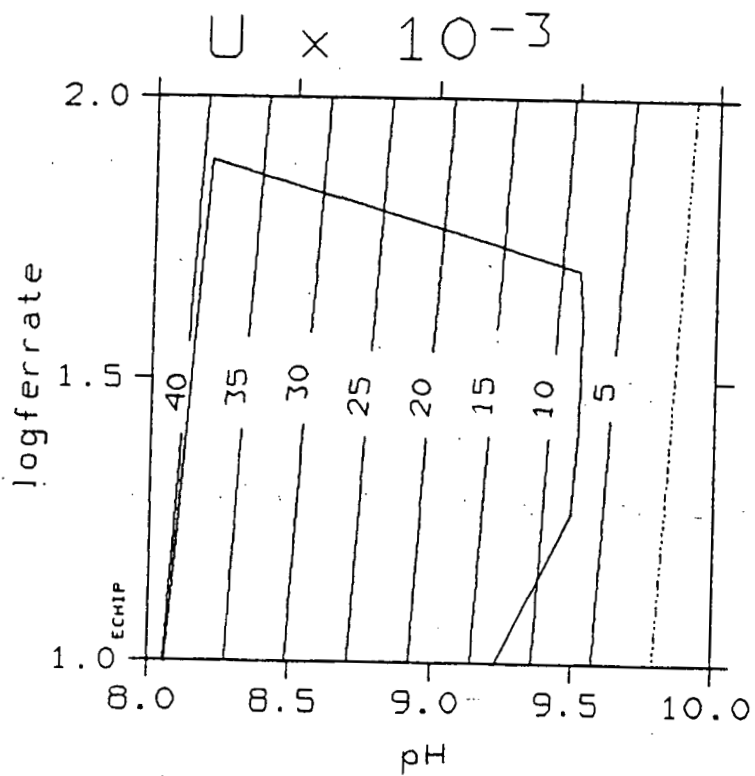
Pu

Lack Of Fit



alum = 27.500000

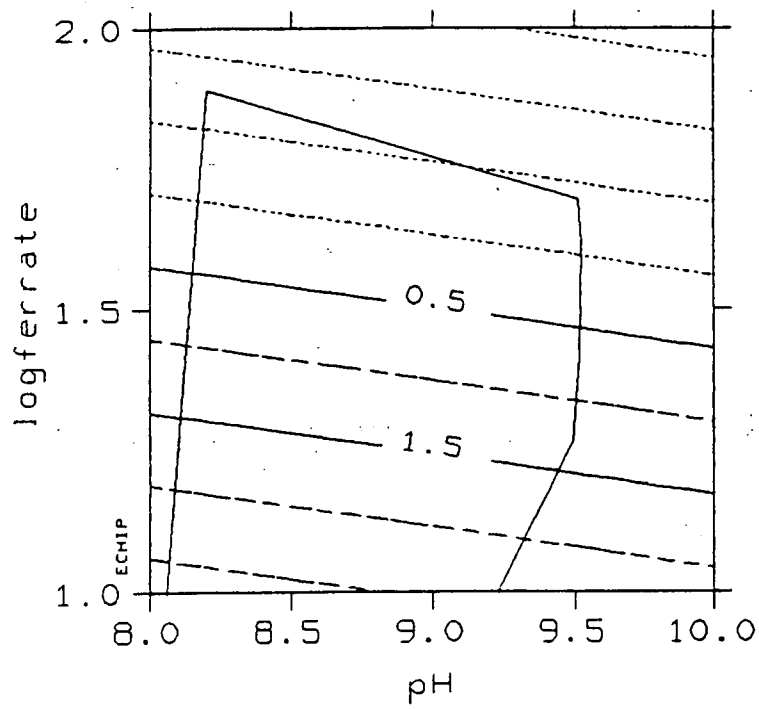
Polymer = 2.5000



alum = 27.500000

Polymer = 2.5000

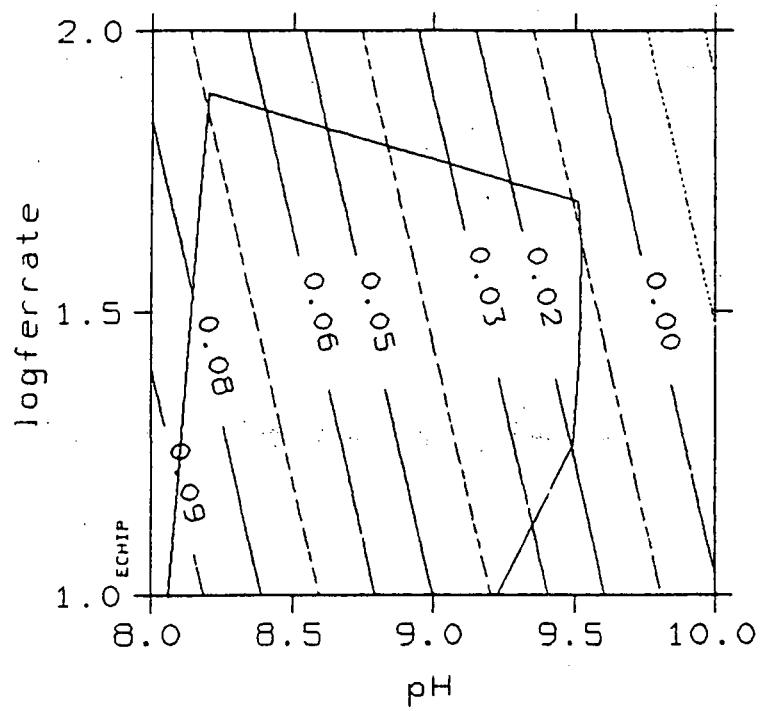
A1



alum = 27.500000

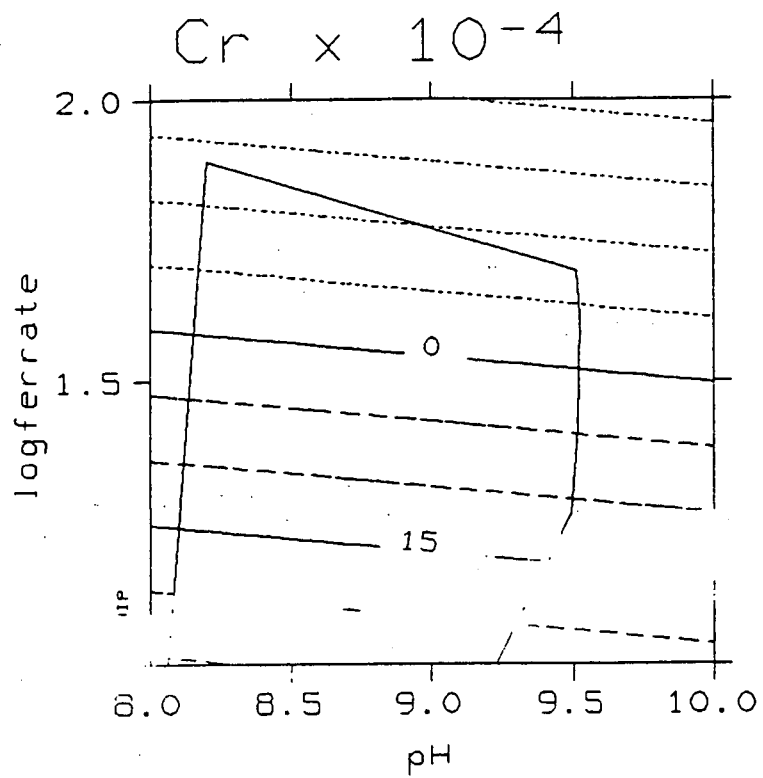
Polymer = 2.5000

Ba



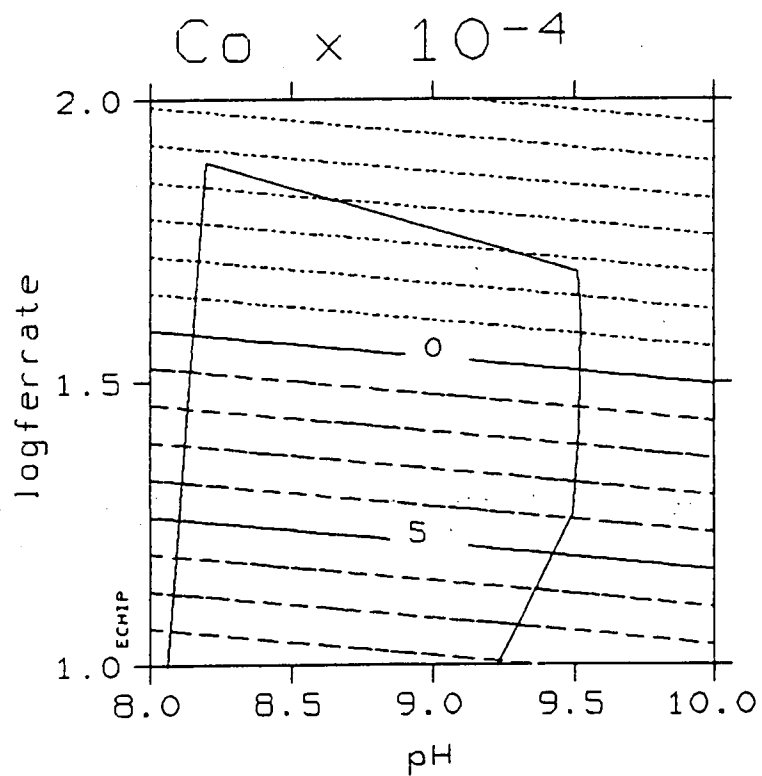
alum = 27.500000

Polymer = 2.5000



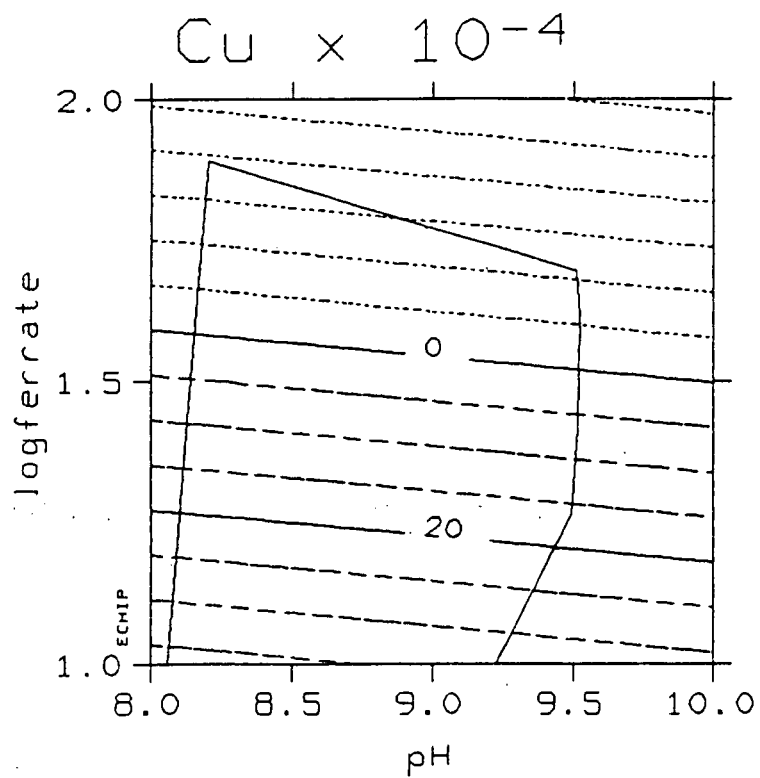
alum = 27.500000

Polymer = 2.5000



alum = 27.500000

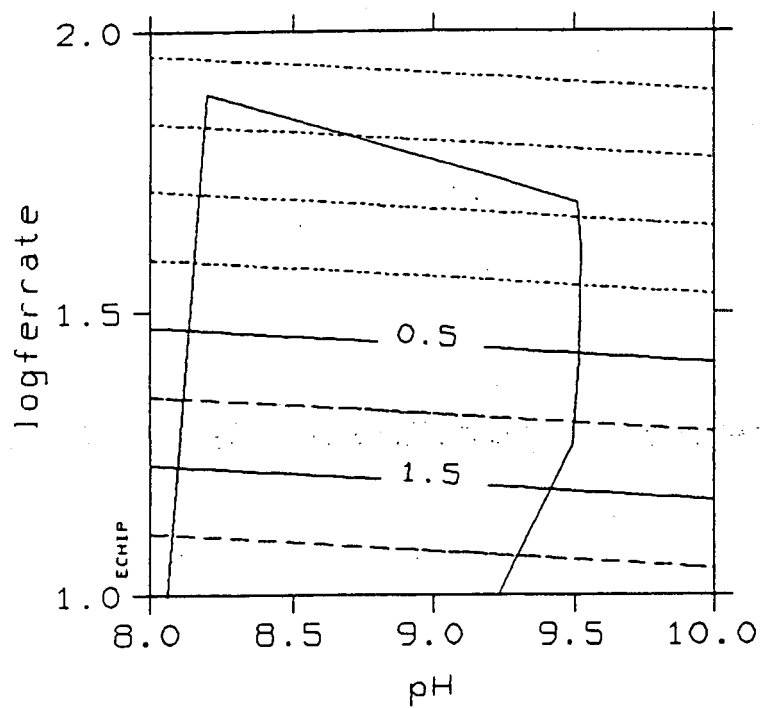
Polymer = 2.5000



alum = 27.500000

Polymer = 2.5000

Fe

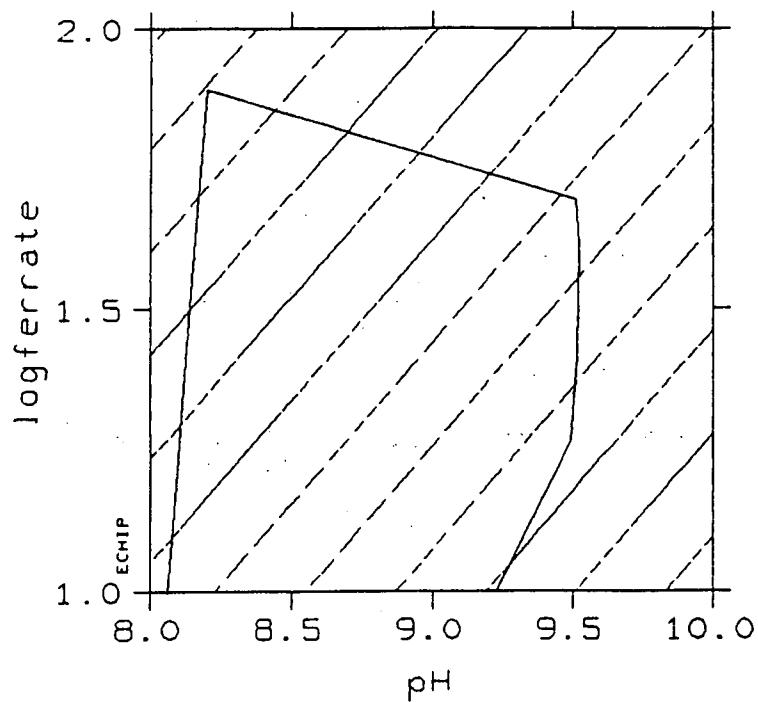


alum = 27.500000

Polymer = 2.5000

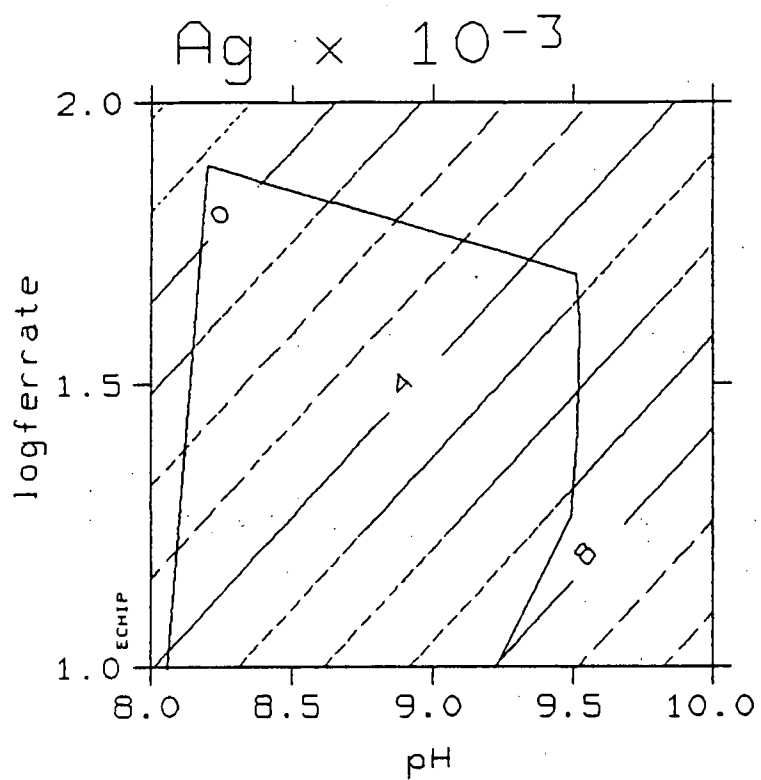
Se

Lack Of Fit



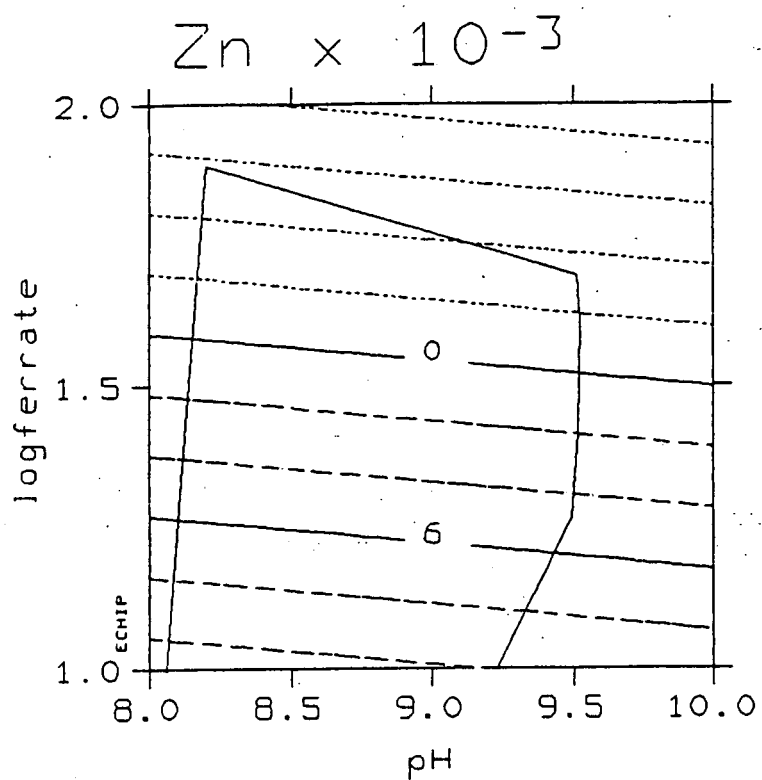
alum = 27.500000

Polymer = 2.5000



alum = 27.500000

Polymer = 2.5000



alum = 27.500000

Polymer = 2.5000

APPENDIX D

PHASE II MODIFIED TEST PLAN

ECHIP DATA OUTPUT

Created: Tue Nov 01 13:48:38 1994

Summary results

Am																				
.	Pu																			
.	.	U																		
.	.	.	Al																	
.	.	.	.	Ba																
.	.	.	.	.	Cr															
.	.	.	.	.	.	Co														
.	.	.	.	.	.	.	Cu													
.	.	.	.	.	.	.	.	Fe												
.	.	.	.	.	.	.	.	.	Se											
.	.	.	.	.	.	.	.	.	.	Ag										
.	.	.	.	.	.	.	.	.	.	.	Zn									

```

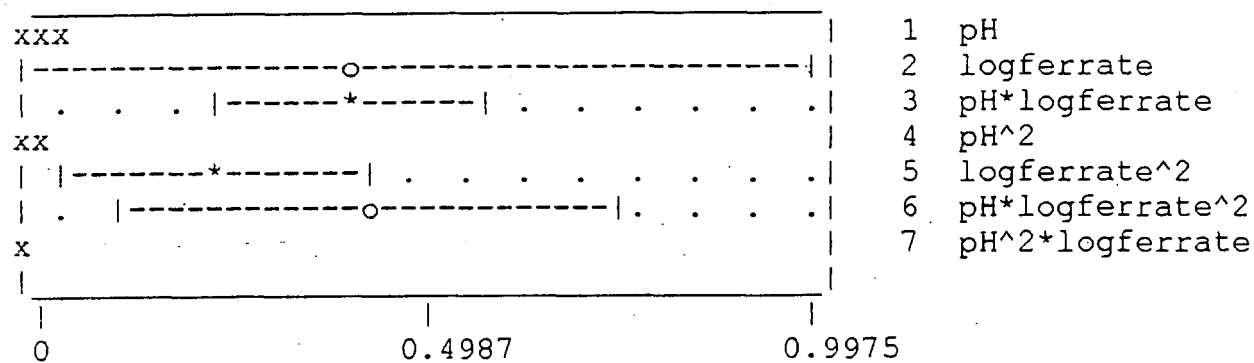
. . *** ***.*** . . . *** . . ** 1 pH
. . ** . * *** . . * 2 logferrate
*** *** . *** *** * . . *** 3 pH*logferrate
. . . * . . . * . . . 4 pH^2
* *** . *** * . . *** 5 logferrate^2
*** *** *** *** *** 6 pH*logferrate^2
. . . . . 7 pH^2*logferrate

```

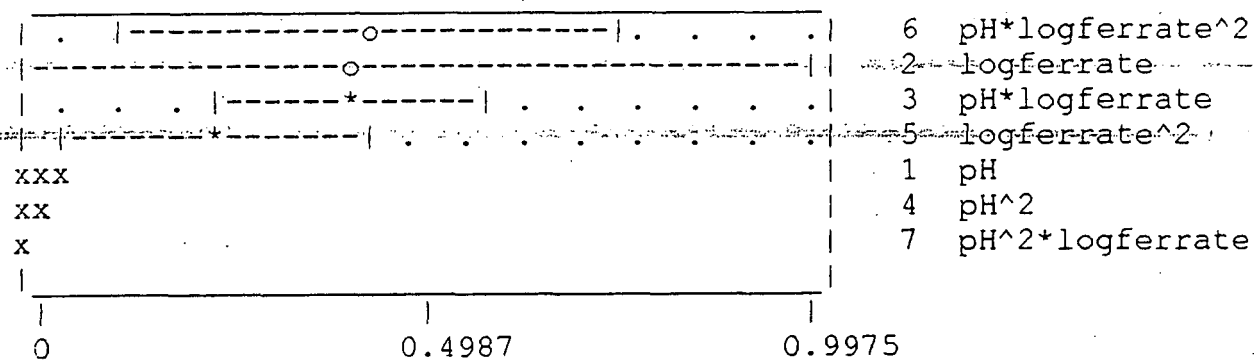
PROJECT NAME: 2NDRF.ECP

Created: Tue Nov 01 13:48:27 1994

«xxxxxxxxxxxx» Effects graph for response 'Am'



Pareto effects graph for response 'Am'



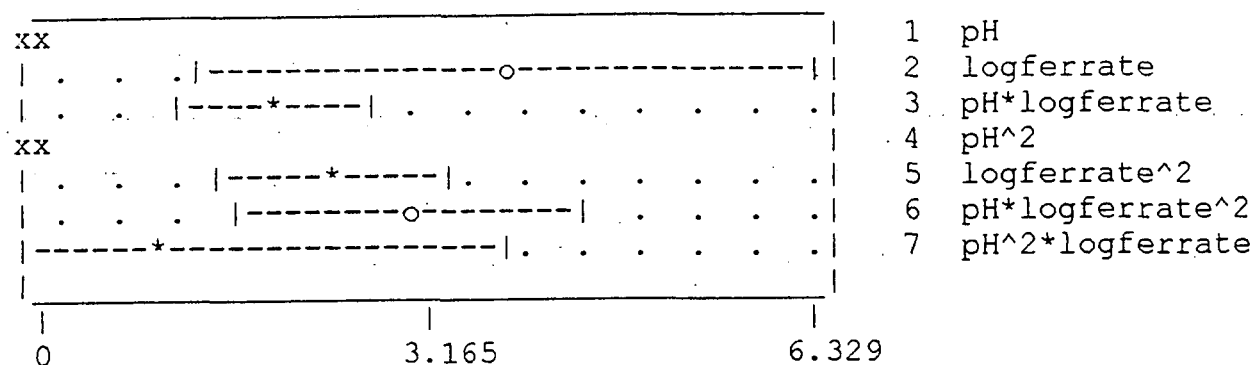
□

137

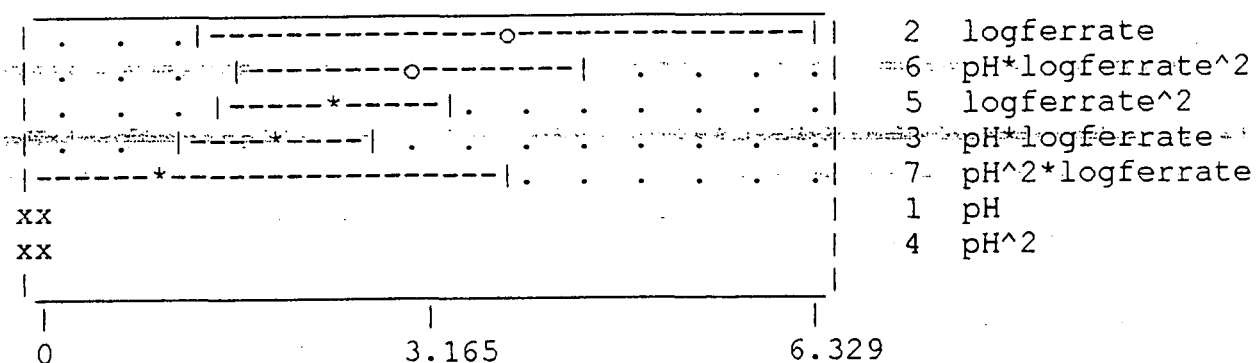
PROJECT NAME: 2NDRF.ECP

Created: Tue Nov 01 13:48:27 1994

«xxxxxxxxxxxx» Effects graph for response 'Pu'



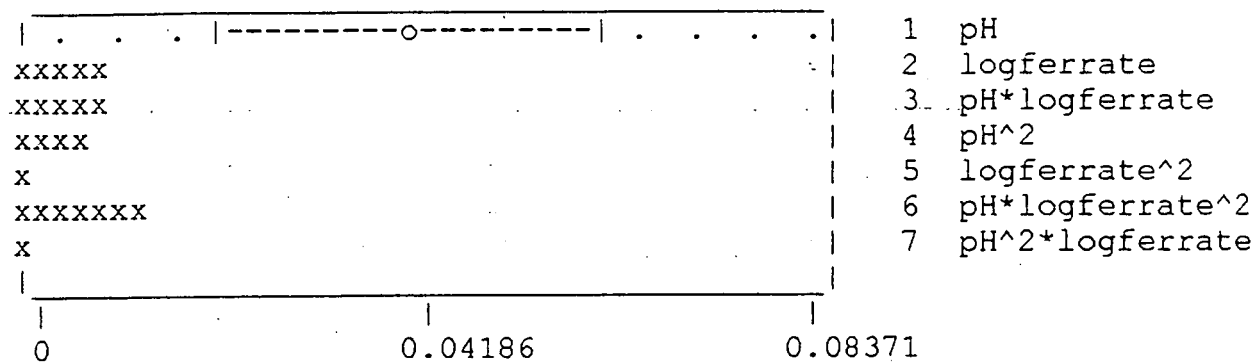
Pareto effects graph for response 'Pu'



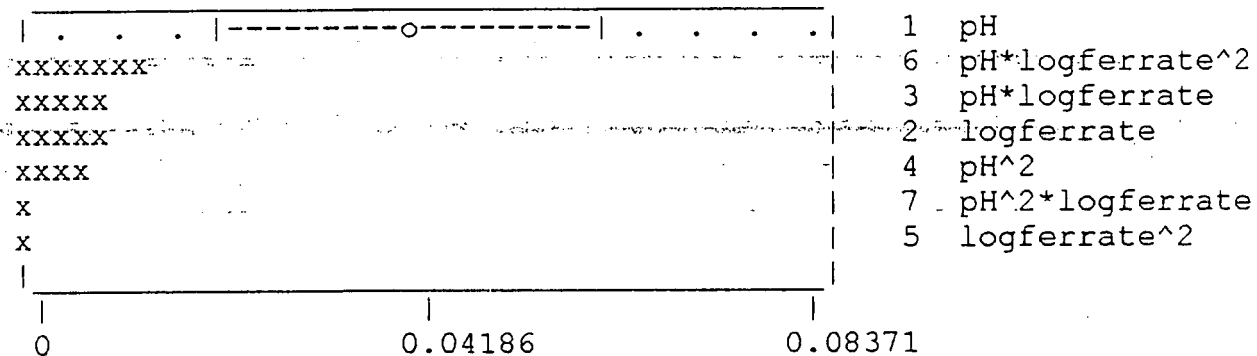
PROJECT NAME: 2NDRF.ECP

Created: Tue Nov 01 13:48:27 1994

«xxxxxxxxxxxx» Effects graph for response 'U'



Pareto effects graph for response 'U'



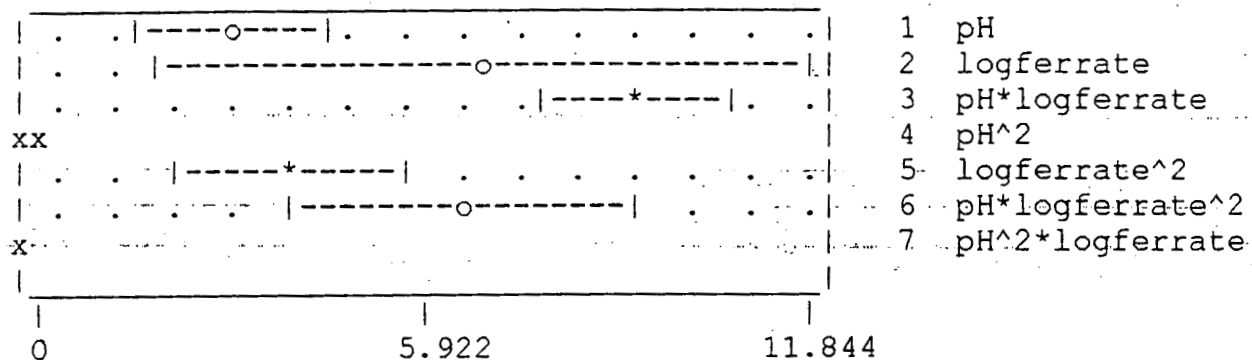
□

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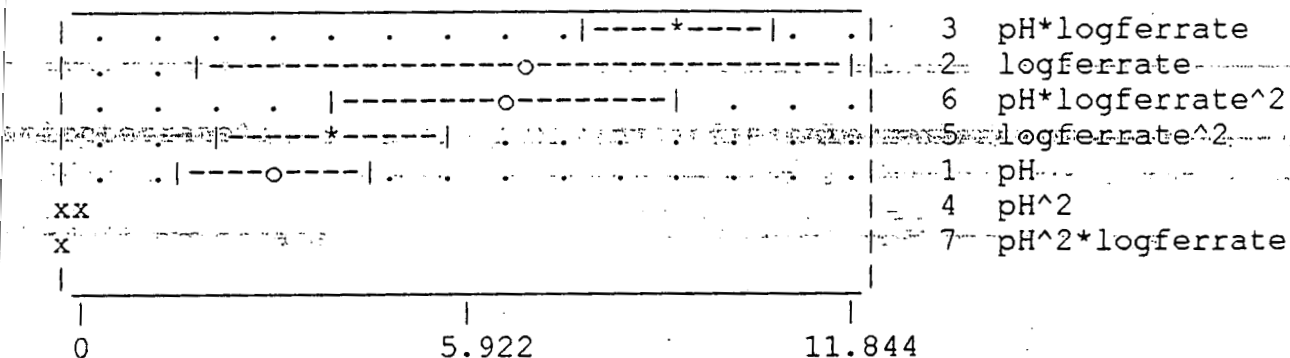
PROJECT NAME: 2NDRF.ECP.

Created: Tue Nov 01 13:48:27 1994

«xxxxxxxxxxxxxx» Effects graph for response 'Al'



Pareto effects graph for response 'Al'



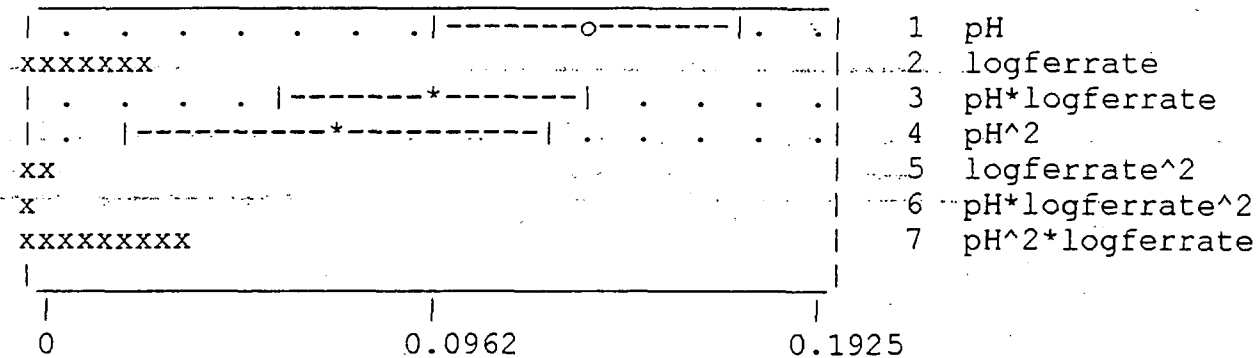
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Created: Tue Nov 01 13:48:27 1994

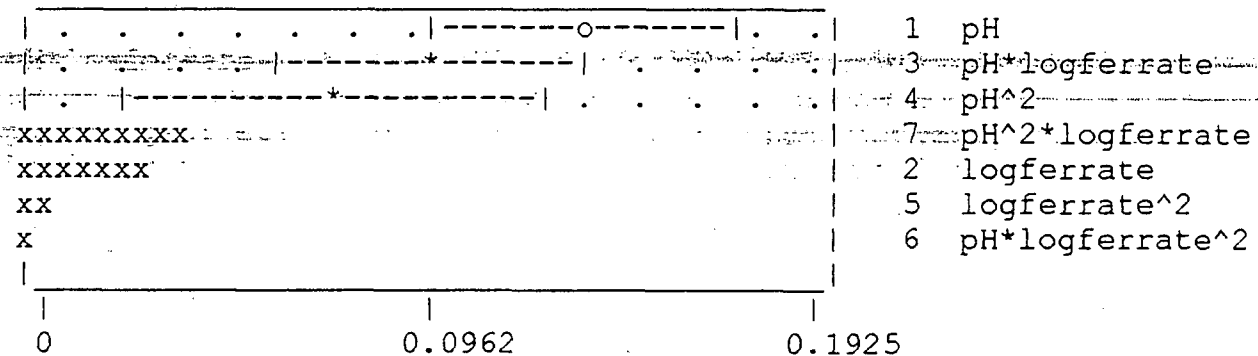
«xxxxxxxxxxxx» Effects graph for response 'Ba'

LACK-OF-FIT



Pareto effects graph for response 'Ba'

LACK-OF-FIT



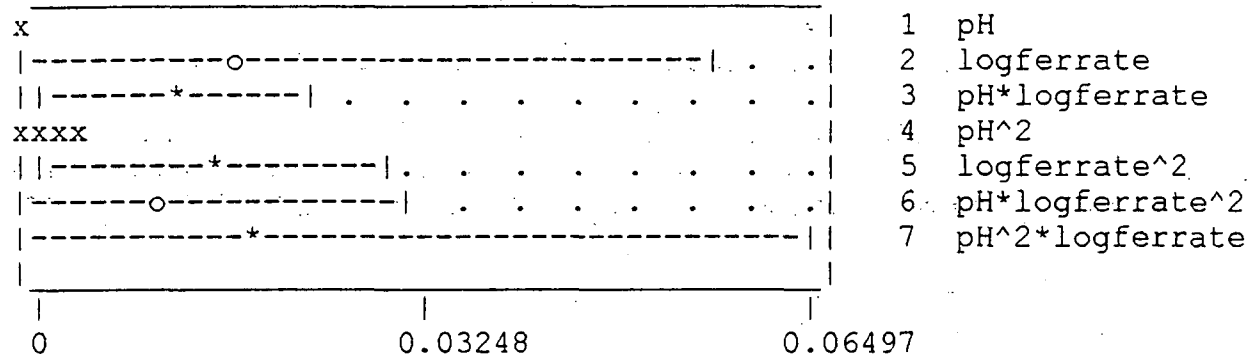
□

PROJECT NAME: 2NDRF.ECP

Created: Tue Nov 01 13:48:27 1994

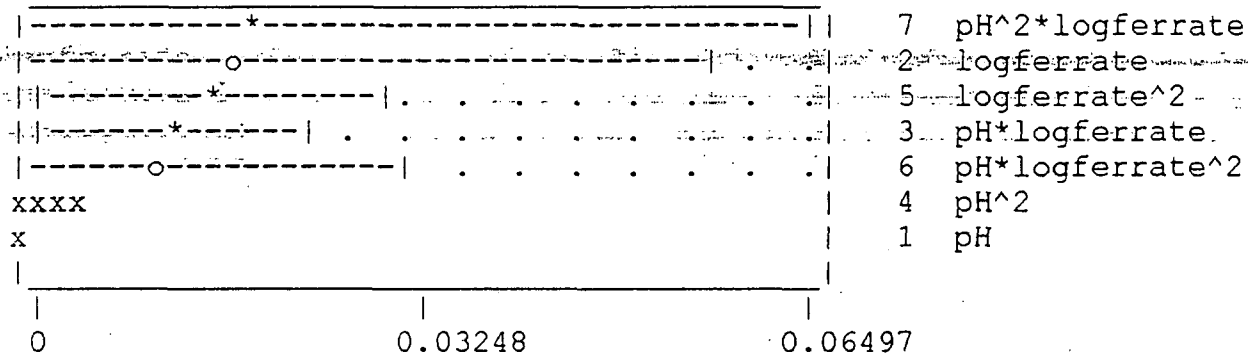
«xxxxxxxxxxxxxx» Effects graph for response 'Cr'

LACK-OF-FIT



Pareto effects graph for response 'Cr'

LACK-OF-FIT



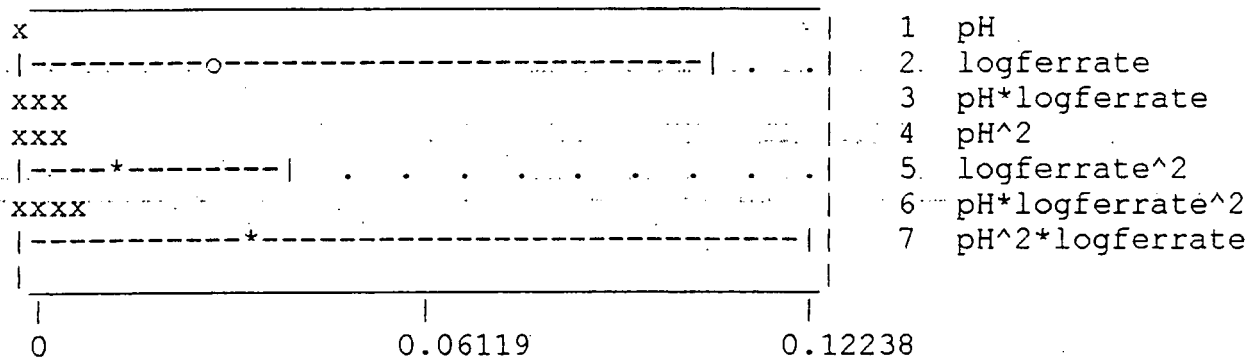
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PROJECT NAME: 2NDRF.ECP

Created: Tue Nov 01 13:48:27 1994

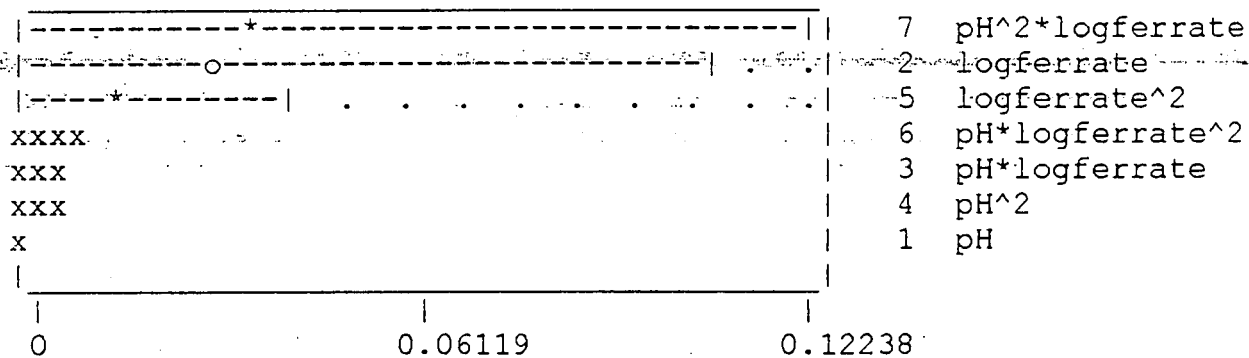
«xxxxxxxxxxxx» Effects graph for response 'Co'

LACK-OF-FIT: Replicates too large



Pareto effects graph for response 'Co'

LACK-OF-FIT: Replicates too large

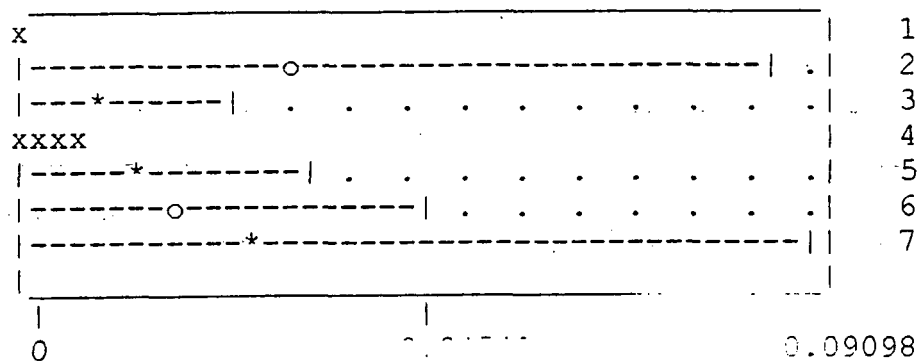


□

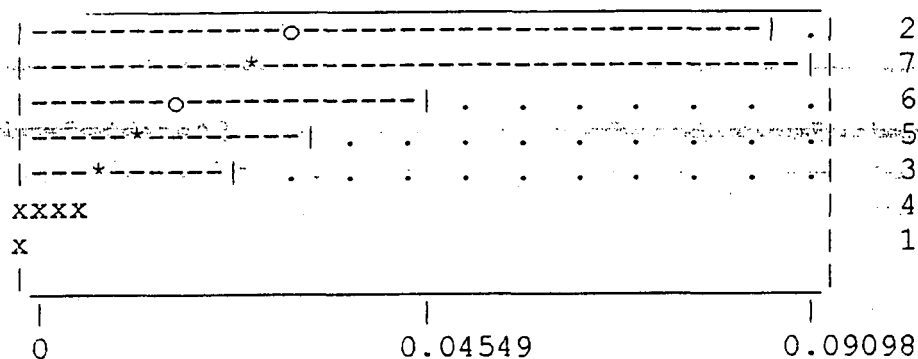
PROJECT NAME: 2NDRF.ECP

Created: Tue Nov 01 13:48:27 1994

«xxxxxxxxxxxx» Effects graph for response 'Cu'



graph for response 'Cu'**



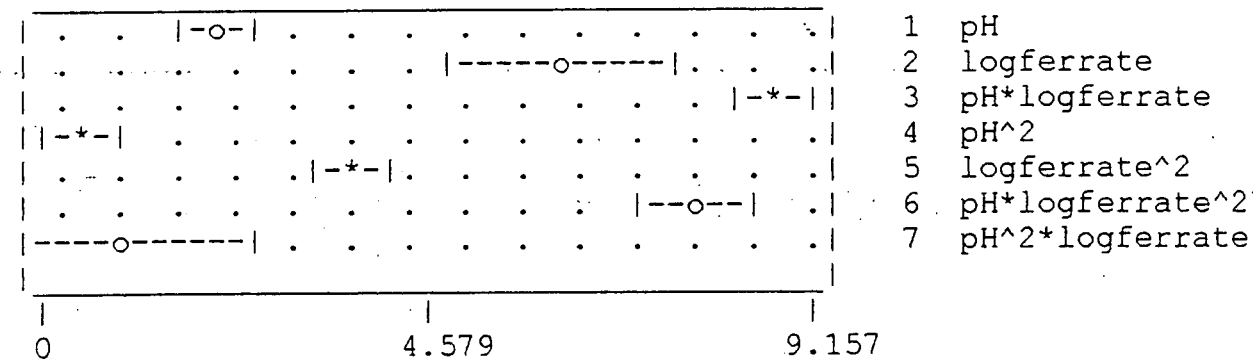
□

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Created: Tue Nov 01 13:48:27 1994

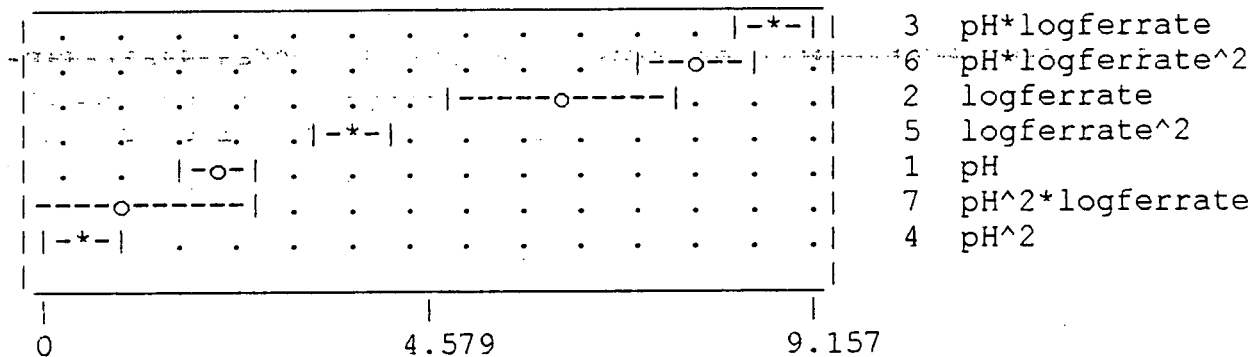
«xxxxxxxxxxxx» Effects graph for response 'Fe'

LACK-OF-FIT



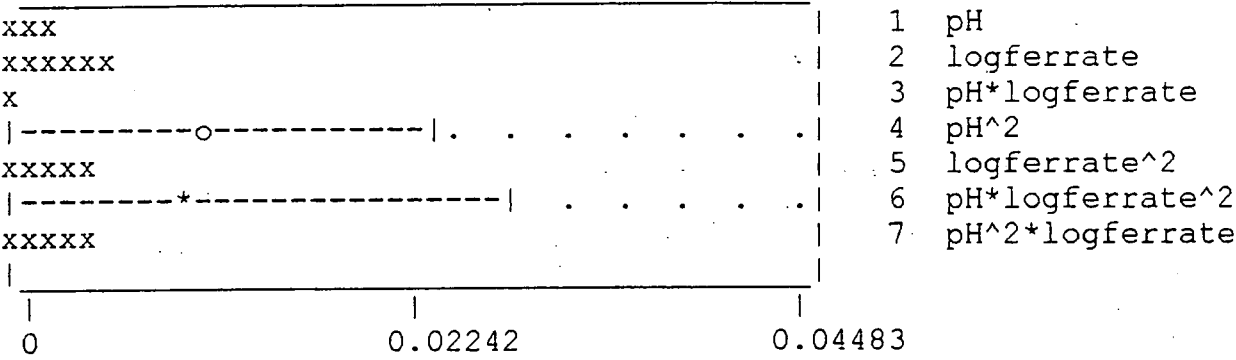
Pareto effects graph for response 'Fe'

LACK-OF-FIT

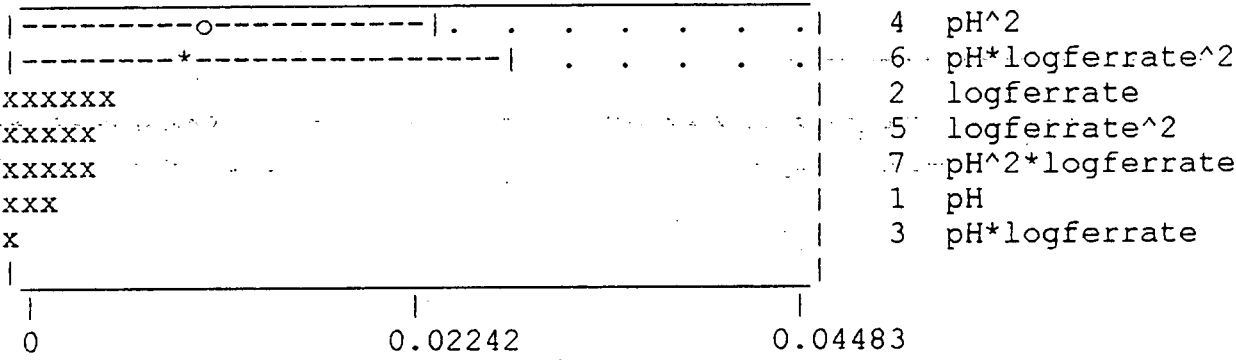


□

«xxxxxxxxxxxxxxxx» Effects graph for response 'Se'



Pareto effects graph for response 'Se'

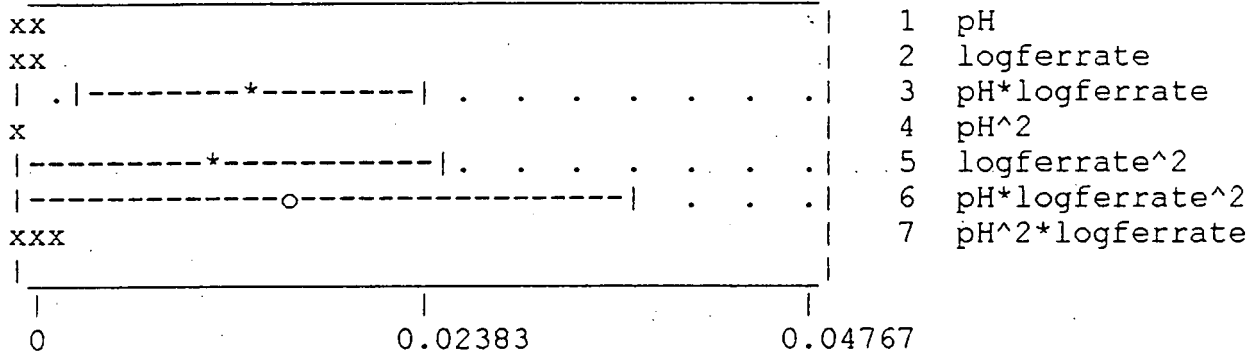


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Created: Tue Nov 01 13:48:27 1994

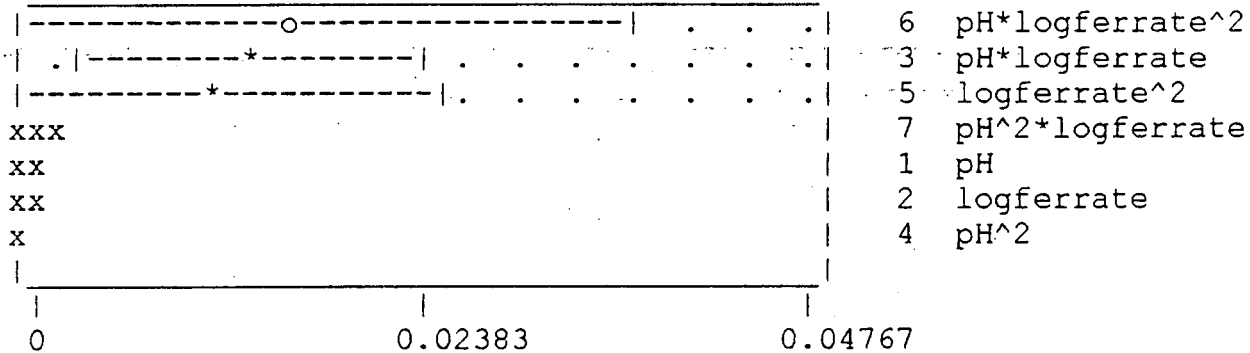
«xxxxxxxxxxxx» Effects graph for response 'Ag'

LACK-OF-FIT



Pareto effects graph for response 'Ag'

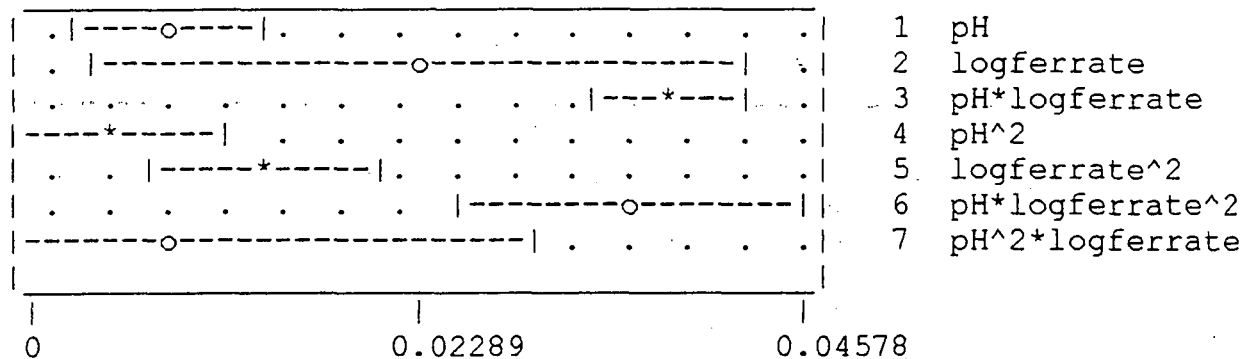
LACK-OF-FIT



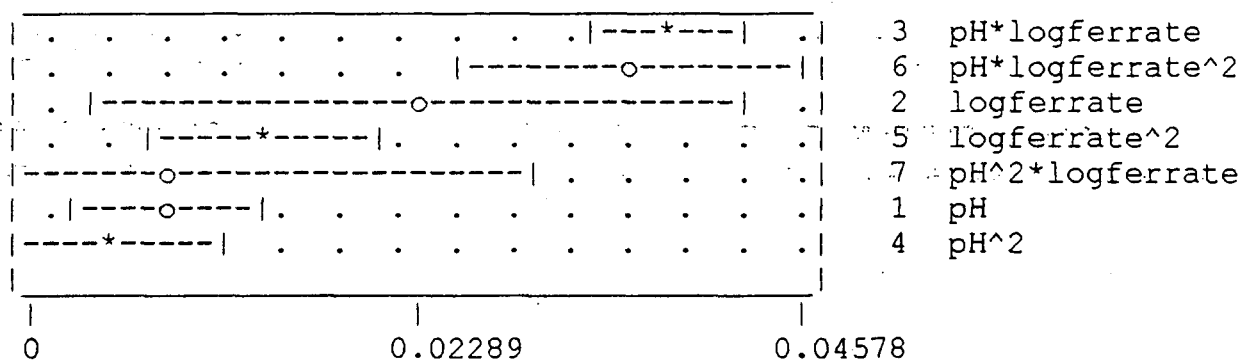
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Created: Tue Nov 01 13:48:27 1994

«xxxxxxxxxxxx» Effects graph for response 'Zn'



Pareto effects graph for response 'Zn'



□

PROJECT NAME: 2NDRF.ECP

Created: Tue Nov 01 13:48:20 1994

«xxxxxxxxxxxxxxxx» Effects for response 'Am'

EFFECTS RESLTN SIG TERM

0.0855		0	CONSTANT
-0.0515	0.2175	1	pH
-0.4179	0.9975	2	logferrate
0.4054	***	3	pH*logferrate
-0.0365	0.2655	4	pH^2
0.2308	*	5	logferrate^2
-0.4475	**	6	pH*logferrate^2
0.0069	0.6680	7	pH^2*logferrate

Residual SD = 0.050912

Replicate SD = 0.064194

N terms = 8

N unique trials = 15

N replicates = 8

N total trials = 23

«xxxxxxxxxxxxxxxx» Effects for response 'Pu'

EFFECTS RESLTN SIG TERM

0.506		0	CONSTANT
-0.315	1.026	1	pH
-3.846	**	2	logferrate
2.043	***	3	pH*logferrate
-0.232	1.213	4	pH^2
2.482	***	5	logferrate^2
-3.045	***	6	pH*logferrate^2
0.972	3.805	7	pH^2*logferrate

Residual SD = 0.218141
Replicate SD = 0.209429

N terms = 8
N unique trials = 15
N replicates = 8
N total trials = 23

«xxxxxxxxxxxxxxxx» Effects for response 'U'

EFFECTS RESLTN SIG TERM

0.01581		0	CONSTANT
-0.04025	***	1	pH
-0.00868	0.08082	2	logferrate
-0.00931	0.02875	3	pH*logferrate
0.00832	0.03682	4	pH^2
0.00095	0.02586	5	logferrate^2
0.01350	0.05157	6	pH*logferrate^2
-0.00143	0.08371	7	pH^2*logferrate

Residual SD = 0.006337
Replicate SD = 0.004837

N terms = 8
N unique trials = 15
N replicates = 8
N total trials = 23

«xxxxxxxxxxxxxxxx» Effects for response 'Al'

EFFECTS RESLTN SIG TERM

0.829		0	CONSTANT
-3.030	***	1	pH
-6.870	*	2	logferrate
9.204	***	3	pH*logferrate
0.522	2.487	4	pH^2
4.048	***	5	logferrate^2

-6.717 *** 6 pH*logferrate^2
0.130 5.804 7 pH^2*logferrate

Residual SD = 0.436947

Replicate SD = 0.541218

N terms = 8

N unique trials = 15

N replicates = 8

N total trials = 23

«xxxxxxxxxxxxxx» Effects for response 'Ba'

LACK-OF-FIT

EFFECTS RESLTN SIG TERM

0.0051 0 CONSTANT

-0.1384 *** 1 pH

-0.0295 0.1621 2 logferrate

0.1003 *** 3 pH*logferrate

0.0723 * 4 pH^2

0.0053 0.0511 5 logferrate^2

-0.0011 0.0711 6 pH*logferrate^2

-0.0412 0.1925 7 pH^2*logferrate

Residual SD = 0.011650

Replicate SD = 0.007638

N terms = 8

N unique trials = 15

N replicates = 8

N total trials = 23

«xxxxxxxxxxxxxx» Effects for response 'Cr'

LACK-OF-FIT

EFFECTS RESLTN SIG TERM

0.00193		0 CONSTANT
-0.00136	0.01297	1 pH
-0.01665	0.05719	2 logferrate
0.01246	*	3 pH*logferrate
-0.00513	0.02114	4 pH^2
0.01618	*	5 logferrate^2
-0.01022	0.03161	6 pH*logferrate^2
0.01872	0.06497	7 pH^2*logferrate

Residual SD = 0.003561

Replicate SD = 0.001458

N terms = 8

N unique trials = 15

N replicates = 8

N total trials = 23

«xxxxxxxxxxxxxx» Effects for response 'Co'

LACK-OF-FIT: Replicates too large

EFFECTS RESLTN SIG TERM

0.00353		0 CONSTANT
0.00285	0.02498	1 pH
-0.03016	0.10743	2 logferrate
-0.00667	0.02749	3 pH*logferrate
-0.00665	0.03717	4 pH^2
0.01414	0.04082	5 logferrate^2
-0.01091	0.05168	6 pH*logferrate^2
0.03425	0.12238	7 pH^2*logferrate

Residual SD = 0.006787

Replicate SD = 0.008664

N terms = 8

N unique trials = 15

N replicates = 8

N total trials = 23

«xxxxxxxxxxxx» Effects for response 'Cu'

EFFECTS RESLTN SIG TERM

0.00554		0	CONSTANT
-0.00198	0.01798		1 pH
-0.03138	0.08724		2 logferrate
0.00856	0.02361		3 pH*logferrate
-0.00692	0.02899		4 pH^2
0.01269	0.03198		5 logferrate^2
-0.01794	0.04742		6 pH*logferrate^2
0.02726	0.09098		7 pH^2*logferrate

Residual SD = 0.004907

Replicate SD = 0.005965

N terms = 8

N unique trials = 15

N replicates = 8

N total trials = 23

«xxxxxxxxxxxx» Effects for response 'Fe'

LACK-OF-FIT

EFFECTS RESLTN SIG TERM

0.736		0	CONSTANT
-2.257	***		1 pH
-6.187	***		2 logferrate
8.814	***		3 pH*logferrate
0.603	*		4 pH^2
3.682	***		5 logferrate^2
-7.793	***		6 pH*logferrate^2
-1.105	2.561		7 pH^2*logferrate

Residual SD = 0.112087

Replicate SD = 0.022958

N terms = 8

Residual SD = 0.003478
Replicate SD = 0.001926

N terms = 8
N unique trials = 15
N replicates = 8
N total trials = 23

«xxxxxxxxxxxxxxxx» Effects for response 'Zn'

EFFECTS RESLTN SIG TERM

0.00246		0	CONSTANT
-0.00842	**	1	pH
-0.02378	*	2	logferrate
0.03833	***	3	pH*logferrate
0.00469 0.01206		4	pH^2
0.01451	***	5	logferrate^2
-0.03594	***	6	pH*logferrate^2
-0.00860 0.02986		7	pH^2*logferrate

Residual SD = 0.001638
Replicate SD = 0.001953

N terms = 8
N unique trials = 15
N replicates = 8
N total trials = 23

N unique trials = 15
N replicates = 8
N total trials = 23

«xxxxxxxxxxxxxx» Effects for response 'Se'

EFFECTS RESLTN SIG TERM

0.06306	0	CONSTANT
0.00257 0.01266	1	pH
-0.00647 0.04170	2	logferrate
0.00007 0.00956	3	pH*logferrate
-0.01042 0.02433	4	pH^2
-0.00492 0.01708	5	logferrate^2
0.00988 0.02848	6	pH*logferrate^2
0.00465 0.04483	7	pH^2*logferrate

Residual SD = 0.003095

Replicate SD = 0.002570

N terms = 8
N unique trials = 15
N replicates = 8
N total trials = 23

«xxxxxxxxxxxxxx» Effects for response 'Ag'

LACK-OF-FIT

EFFECTS RESLTN SIG TERM

0.00178	0	CONSTANT
0.00218 0.01352	1	pH
0.00152 0.04111	2	logferrate
0.01365 *	3	pH*logferrate
-0.00084 0.01648	4	pH^2
0.01157 0.02524	5	logferrate^2
-0.01618 0.03707	6	pH*logferrate^2
-0.00251 0.04767	7	pH^2*logferrate

PROJECT NAME: 2NDRF.ECP

Created: Tue Nov 01 13:48:12 1994

«xxxxxxxxxxxx» Coefficients for response 'Am'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
--------------	----	---	-----------	------

0.0855279			0	CONSTANT
-----------	--	--	---	----------

-0.0132024	0.0199677	0.5185-	0.386	1 pH
------------	-----------	---------	-------	------

-0.0803609	0.0522942	0.1452	0.125	2 logferrate
------------	-----------	--------	-------	--------------

0.0346454	0.0062613	0.0001	0.586	3 pH*logferrate
-----------	-----------	--------	-------	-----------------

-0.00915689	0.0269247	0.7385-	0.283	4 pH^2
-------------	-----------	---------	-------	--------

0.0256417	0.0104322	0.0266	0.387	5 logferrate^2
-----------	-----------	--------	-------	----------------

-0.0127492	0.00408845	0.0070	0.363	6 pH*logferrate^2
------------	------------	--------	-------	-------------------

0.00038119	0.0170979	0.9825-	0.119	7 pH^2*logferrate
------------	-----------	---------	-------	-------------------

N trials = 23

N terms = 8

Residual SD = 0.050912

Residual DF = 15

Residual SD used for tests

Replicate SD = 0.064194

Replicate DF = 8

R Squared = 0.978, P=0.0000 ***

Adj R Squared = 0.967

Maximum Cook-Weisberg LD influence (scaled 0-1) = 0.020

- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'Pu'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
--------------	----	---	-----------	------

0.505624			0	CONSTANT
----------	--	--	---	----------

-0.0807439	0.0855555	0.3602-	0.386	1 pH
------------	-----------	---------	-------	------

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-0.739537	0.224064	0.0049	0.125	2 logferrate
0.174586	0.0268277	0.0000	0.586	3 pH*logferrate
-0.0580942	0.115364	0.6219-	0.283	4 pH^2
0.275792	0.0446987	0.0000	0.387	5 logferrate^2
-0.0867403	0.0175177	0.0002	0.363	6 pH*logferrate^2
0.0536005	0.0732591	0.4757	0.119	7 pH^2*logferrate

N trials = 23

N terms = 8

Residual SD = 0.218141

Residual DF = 15

Residual SD used for tests

Replicate SD = 0.209429

Replicate DF = 8

R Squared = 0.992, P=0.0000 ***

Adj R Squared = 0.988

Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

- This term may be eliminated

«xxxxxxxxxxxxxx» Coefficients for response 'U'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.0158053			0	CONSTANT
-0.0103195	0.00248531	0.0009	0.386	1 pH
-0.00166904	0.00650886	0.8011-	0.125	2 logferrate
-0.000795818	0.00077932	0.3234-	0.586	3 pH*logferrate
0.00208594	0.00335121	0.5430-	0.283	4 pH^2
0.000105974	0.00129846	0.9360-	0.387	5 logferrate^2
0.000384568	0.000508874	0.4615-	0.363	6 pH*logferrate^2
-7.88849e-005	0.00212811	0.9709-	0.119	7 pH^2*logferrate

N trials = 23

N terms = 8

Residual SD = 0.006337

Residual DF = 15

Residual SD used for tests

Replicate SD = 0.004837

Replicate DF = 8

R Squared = 0.882, P=0.0000 ***

Adj R Squared = 0.827

Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

- This term may be eliminated

«XXXXXXXXXXXX» Coefficients for response 'Al'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
--------------	----	---	-----------	------

0.829257			0	CONSTANT
----------	--	--	---	----------

-0.776877	0.171372	0.0004	0.386	1 pH
-----------	----------	--------	-------	------

-1.32112	0.448813	0.0101	0.125	2 logferrate
----------	----------	--------	-------	--------------

0.786633	0.0537372	0.0000	0.586	3 pH*logferrate
----------	-----------	--------	-------	-----------------

0.130862	0.23108	0.5796	0.283	4 pH^2
----------	---------	--------	-------	--------

0.449755	0.0895338	0.0002	0.387	5 logferrate^2
----------	-----------	--------	-------	----------------

-0.191373	0.035089	0.0001	0.363	6 pH*logferrate^2
-----------	----------	--------	-------	-------------------

0.00719295	0.146742	0.9616	0.119	7 pH^2*logferrate
------------	----------	--------	-------	-------------------

N trials = 23

N terms = 8

Residual SD = 0.436947

Residual DF = 15

Residual SD used for tests

Replicate SD = 0.541218

Replicate DF = 8

R Squared = 0.996, P=0.0000 ***

Adj R Squared = 0.994

Maximum Cook-Weisberg LD influence (scaled 0-1) = 0.004

- This term may be eliminated

«XXXXXXXXXXXX» Coefficients for response 'Ba'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
--------------	----	---	-----------	------

0.00508681			0	CONSTANT
-0.0354767	0.0045692	0.0000	0.386	1 pH
-0.00566416	0.0119664	0.6428-	0.125	2 logferrate
0.00857104	0.00143277	0.0000	0.586	3 pH*logferrate
0.0181111	0.00616115	0.0101	0.283	4 pH^2
0.000588895	0.00238719	0.8085-	0.387	5 logferrate^2
-3.21478e-005	0.000935557	0.9730-	0.363	6 pH*logferrate^2
-0.00227272	0.00391249	0.5699-	0.119	7 pH^2*logferrate

N trials = 23

N terms = 8

Residual SD = 0.011650, Lack-Of-Fit P=0.0392 *

Residual DF = 15

Residual SD used for tests

Replicate SD = 0.007638

Replicate DF = 8

R Squared = 0.983, P=0.0000 ***

Adj R-Squared = 0.975

Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'Cr'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
--------------	----	---	-----------	------

0.00192824			0	CONSTANT
-0.000349606	0.00139669	0.8057-	0.386	1 pH
-0.00320234	0.00365786	0.3951	0.125	2 logferrate
0.00106513	0.000437963	0.0280	0.586	3 pH*logferrate
-0.00128459	0.00188332	0.5056-	0.283	4 pH^2
0.00179797	0.000729707	0.0263	0.387	5 logferrate^2
-0.000291075	0.000285978	0.3249	0.363	6 pH*logferrate^2
0.00103225	0.00119596	0.4017	0.119	7 pH^2*logferrate

N trials = 23

N terms = 8

Residual SD = 0.003561, Lack-Of-Fit P=0.0012 **

Residual DF = 15

Residual SD used for tests

Replicate SD = 0.001458

Replicate DF = 8

R Squared = 0.821, P=0.0001 ***

Adj R Squared = 0.737

Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

- This term may be eliminated

«xxxxxxxxxxxxxxxx» Coefficients for response

Centered continuous variables

COEFFICIENTS SD P CONDITION TERM

0.00353368

0 CONSTANT

0.000730427 0.00266198 0.7875 0.386 1 pH

-0.00579985 0.00697156 0.4185 0.125 2 logferrate

-0.000570431 0.00083472 0.5048 0.586 3 pH*logferrate

-0.00166572 0.00358944 0.6493 0.283 4 pH^2

0.00157075 0.00139076 0.2765 0.387 5 logferrate^2

-0.00031069 0.000545049 0.5771 0.363 6 pH*logferrate^2

0.00188815 0.00227939 0.4205 0.119 7 pH^2*logferrate

N trials = 23

N terms = 8

Residual SD = 0.006787, Lack-Of-Fit (Residual SD too small) P=0.9842

Residual DF = 15

Residual SD used for tests

Replicate SD = 0.008664

Replicate DF = 8

R Squared = 0.262, P=0.6286

Adj R Squared = 0.000

Maximum Cook-Weisberg LD influence (scaled 0-1) = 0.114

- This term may be eliminated

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«xxxxxxxxxxxx» Coefficients for response 'Cu'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.00553942			0	CONSTANT
-0.00050666	0.00192467	0.7959	0.386	1 pH
-0.00603385	0.00504059	0.2499	0.125	2 logferrate
0.000731448	0.000603521	0.2443	0.586	3 pH*logferrate
-0.0017336	0.00259525	0.5143	0.283	4 pH^2
0.00140995	0.00100555	0.1812	0.387	5 logferrate^2
-0.000511024	0.000394082	0.2143	0.363	6 pH*logferrate^2
0.001503	0.00164805	0.3762	0.119	7 pH^2*logferrate

N trials = 23

N terms = 8

Residual SD = 0.004907

Residual DF = 15

Residual SD used for tests

Replicate SD = 0.005965

Replicate DF = 8

R Squared = 0.766, P=0.0008 ***

Adj R Squared = 0.656

Maximum Cook-Weisberg LD influence (scaled 0-1) = 0.733

- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'Fe'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.73601			0	CONSTANT
-0.578731	0.0439609	0.0000	0.386	1 pH
-1.18978	0.115131	0.0000	0.125	2 logferrate
0.7533	0.0137849	0.0000	0.586	3 pH*logferrate
0.15101	0.0592773	0.0223	0.283	4 pH^2
0.409111	0.0229675	0.0000	0.387	5 logferrate^2
-0.222022	0.00900114	0.0000	0.363	6 pH*logferrate^2
-0.0609325	0.0376427	0.1263	0.119	7 pH^2*logferrate

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N trials = 23
N terms = 8

Residual SD = 0.112087, Lack-Of-Fit P=0.0000 ***
Residual DF = 15
Residual SD used for tests

Replicate SD = 0.022958
Replicate DF = 8

R Squared = 1.000, P=0.0000 ***
Adj R Squared = 1.000
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

«xxxxxxxxxxxx» Coefficients for response 'Se'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.063064			0	CONSTANT
0.000660229	0.00121369	0.5944-	0.386	1 pH
-0.00124334	0.00317857	0.7012-	0.125	2 logferrate
6.10894e-006	0.000380577	0.9874-	0.586	3 pH*logferrate
-0.00261039	0.00163655	0.1315	0.283	4 pH^2
-0.000546443	0.000634094	0.4024-	0.387	5 logferrate^2
0.000281589	0.000248506	0.2749	0.363	6 pH*logferrate^2
0.000256357	0.00103925	0.8085-	0.119	7 pH^2*logferrate

N trials = 23
N terms = 8

Residual SD = 0.003095
Residual DF = 15
Residual SD used for tests

Replicate SD = 0.002570
Replicate DF = 8

R Squared = 0.812, P=0.0002 ***
Adj R Squared = 0.725
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

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- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'Ag'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
--------------	----	---	-----------	------

0.00178335			0	CONSTANT
-0.000558064	0.00136412	0.6882	0.386	1 pH
0.000291669	0.00357255	0.9360	0.125	2 logferrate
0.0011668	0.000427748	0.0156	0.586	3 pH*logferrate
-0.000210101	0.00183939	0.9106	0.283	4 pH^2
0.00128576	0.000712689	0.0913	0.387	5 logferrate^2
-0.000460847	0.000279308	0.1197	0.363	6 pH*logferrate^2
-0.000138155	0.00116806	0.9074	0.119	7 pH^2*logferrate

N trials = 23

N terms = 8

Residual SD = 0.003478, Lack-Of-Fit P=0.0118 *

Residual DF = 15

Residual SD used for tests

Replicate SD = 0.001926

Replicate DF = 8

R Squared = 0.863, P=0.0000 ***

Adj R Squared = 0.799

Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'Zn'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
--------------	----	---	-----------	------

0.00245686			0	CONSTANT
-0.00215909	0.000642332	0.0043	0.386	1 pH
-0.00457306	0.00168223	0.0159	0.125	2 logferrate
0.00327574	0.000201417	0.0000	0.586	3 pH*logferrate
0.0011765	0.000866127	0.1944	0.283	4 pH^2

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0.00161198	0.000335588	0.0002	0.387	5 logferrate^2
-0.00102404	0.00013152	0.0000	0.363	6 pH*logferrate^2
-0.00047393	0.000550014	0.4024	0.119	7 pH^2*logferrate

N trials = 23

N terms = 8

Residual SD = 0.001638

Residual DF = 15

Residual SD used for tests

Replicate SD = 0.001953

Replicate DF = 8

R Squared = 0.997, P=0.0000 ***

Adj R Squared = 0.995

Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

- This term may be eliminated

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PROJECT NAME: 2NDRF.ECP

Created: Tue Nov 01 13:48:37 1994

«xxxxxxxxxxxxxx» ANOVA Table for response 'Am'

Mean Squares DF P

0.000845217	2	0.7267	pH
0.00880949	2	0.0606	logferrate
0.143452	3	0.0000	pH*logferrate
0.00259201	15		ERROR
0.00412083	8		REPLICATE ERROR

«xxxxxxxxxxxxxx» ANOVA Table for response 'Pu'

Mean Squares DF P

0.0322025	2	0.5231	pH
1.1446	2	0.0000	logferrate
4.40219	3	0.0000	pH*logferrate
0.0475854	15		ERROR
0.0438604	8		REPLICATE ERROR

«xxxxxxxxxxxxxx» ANOVA Table for response 'U'

Mean Squares DF P

0.000346394	2	0.0032	pH
2.38225e-006	2	0.9426	logferrate
9.20154e-005	3	0.1198	pH*logferrate
4.01549e-005	15		ERROR
2.33996e-005	8		REPLICATE ERROR

«xxxxxxxxxxxxxx» ANOVA Table for response 'Al'

Mean Squares DF P

1.96707	2	0.0015	pH
2.84013	2	0.0003	logferrate
57.8535	3	0.0000	pH*logferrate
0.190923	15		ERROR

0.292917 8 REPLICATE ERROR

«xxxxxxxxxxxxxx» ANOVA Table for response 'Ba'

LACK-OF-FIT

Mean Squares DF P

0.00426438	2	0.0000	pH
1.96029e-005	2	0.8667	logferrate
0.00430042	3	0.0000	pH*logferrate
0.000135724	15		ERROR

5.83333e-005 8 REPLICATE ERROR

«xxxxxxxxxxxxxx» ANOVA Table for response 'Cr'

LACK-OF-FIT

Mean Squares DF P

3.84755e-006	2	0.7427	pH
6.51058e-005	2	0.0200	logferrate
9.73178e-005	3	0.0024	pH*logferrate
1.26818e-005	15		ERROR

2.125e-006 8 REPLICATE ERROR

«xxxxxxxxxxxxxx» ANOVA Table for response 'Co'

LACK-OF-FIT: Replicates too large

Mean Squares DF P

file

5.84316e-006	2	0.8818	pH
3.01016e-005	2	0.5344	logferrate
2.25227e-005	3	0.6952	pH*logferrate
4.60669e-005	15		ERROR
7.50625e-005	8		REPLICATE ERROR

«xxxxxxxxxxxxxxxx» ANOVA Table for response 'Cu'

Mean Squares	DF	P
7.17466e-006	2	0.7466
2.37343e-005	2	0.3961
9.10799e-005	3	0.0334
2.40819e-005	15	
3.55833e-005	8	

7.17466e-006	2	0.7466	pH
2.37343e-005	2	0.3961	logferrate
9.10799e-005	3	0.0334	pH*logferrate
2.40819e-005	15		ERROR
3.55833e-005	8		REPLICATE ERROR

«xxxxxxxxxxxxxxxx» ANOVA Table for response 'Fe'

LACK-OF-FIT

Mean Squares	DF	P
1.08903	2	0.0000
2.36762	2	0.0000
59.825	3	0.0000
0.0125635	15	
0.000527083	8	

1.08903	2	0.0000	pH
2.36762	2	0.0000	logferrate
59.825	3	0.0000	pH*logferrate
0.0125635	15		ERROR
0.000527083	8		REPLICATE ERROR

«xxxxxxxxxxxxxxxx» ANOVA Table for response 'Se'

Mean Squares	DF	P
1.25244e-005	2	0.2995
2.17754e-005	2	0.1372
1.18247e-005	3	0.3318
9.57617e-006	15	
6.60417e-006	8	

1.25244e-005	2	0.2995	pH
2.17754e-005	2	0.1372	logferrate
1.18247e-005	3	0.3318	pH*logferrate
9.57617e-006	15		ERROR
6.60417e-006	8		REPLICATE ERROR

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«xxxxxxxxxxxxxx» ANOVA Table for response 'Ag'

LACK-OF-FIT

Mean Squares DF P

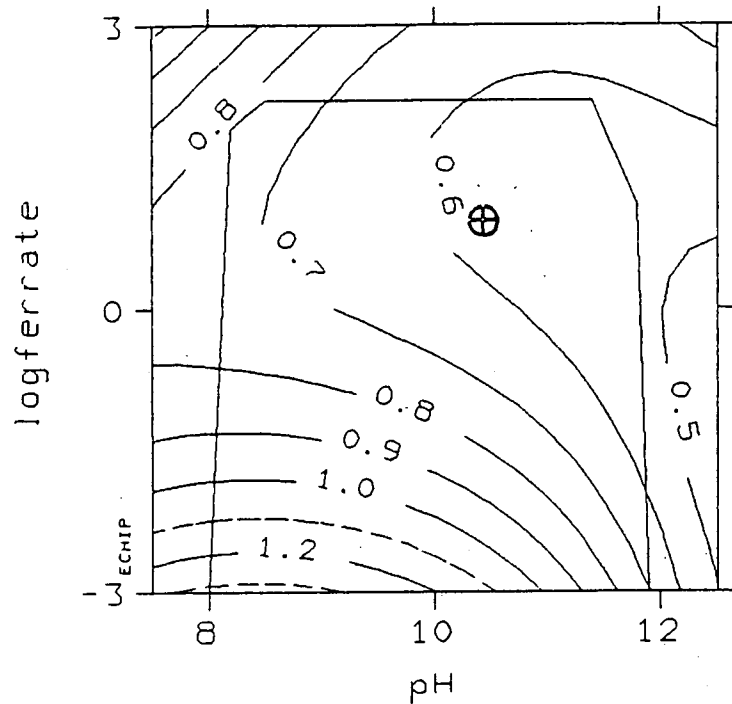
1.02345e-006	2	0.9193	pH
6.63965e-005	2	0.0163	logferrate
0.000174763	3	0.0001	pH*logferrate
1.20972e-005	15		ERROR
3.70833e-006	8		REPLICATE ERROR

«xxxxxxxxxxxxxx» ANOVA Table for response 'Zn'

Mean Squares DF P

1.59665e-005	2	0.0125	pH
3.74525e-005	2	0.0004	logferrate
0.00118497	3	0.0000	pH*logferrate
2.68224e-006	15		ERROR
3.8125e-006	8		REPLICATE ERROR

Default

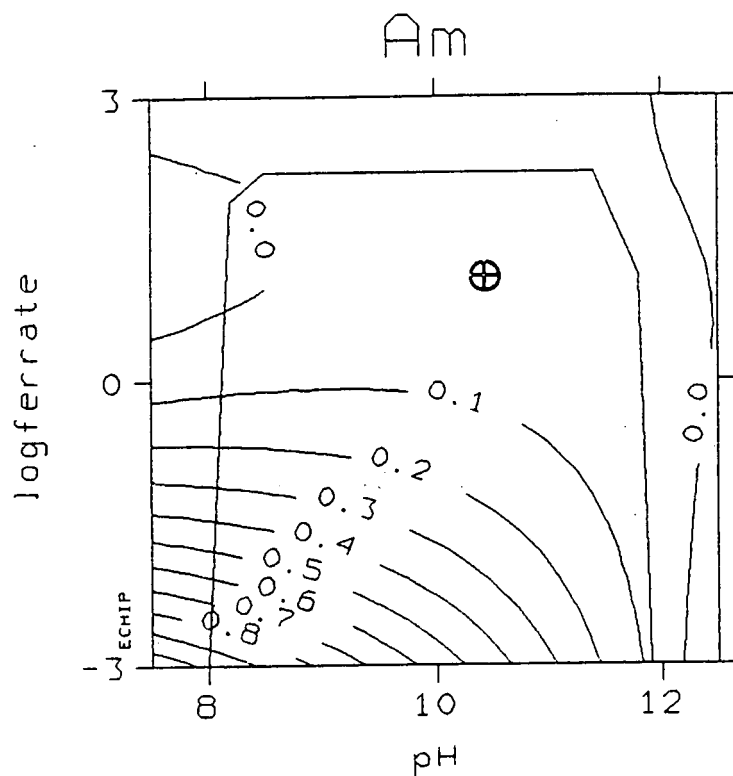


pH=10.35

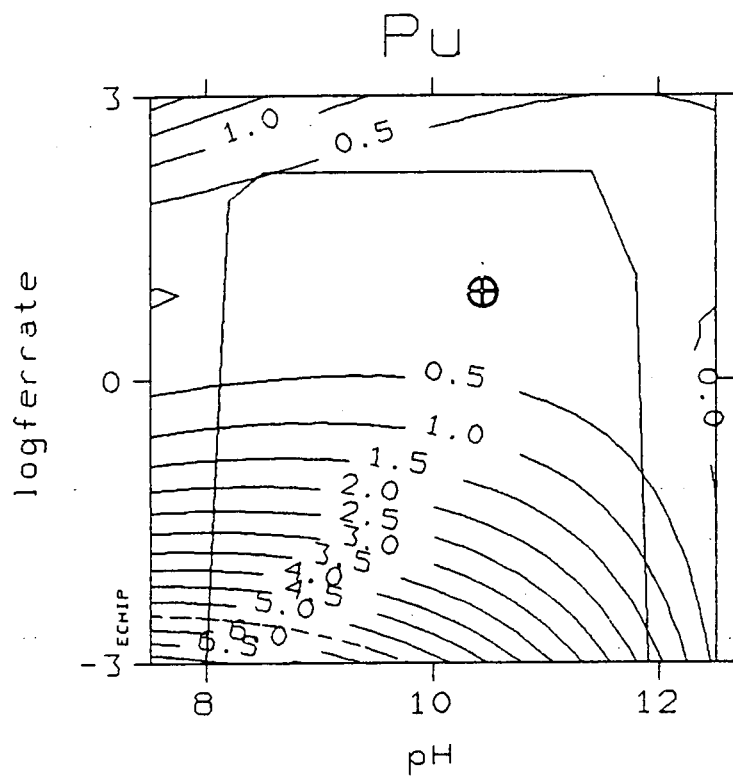
logferrate=1.02

Value

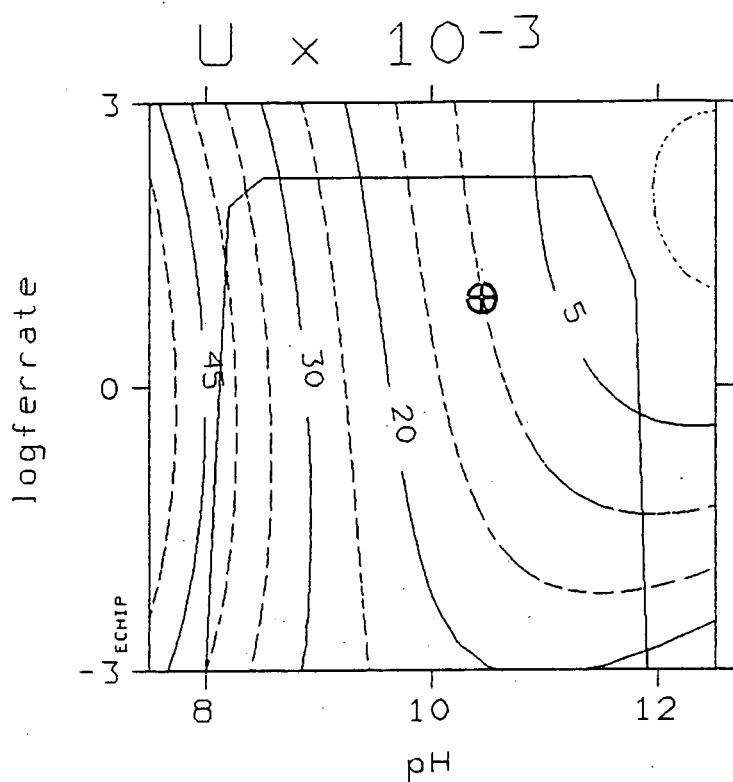
0.58



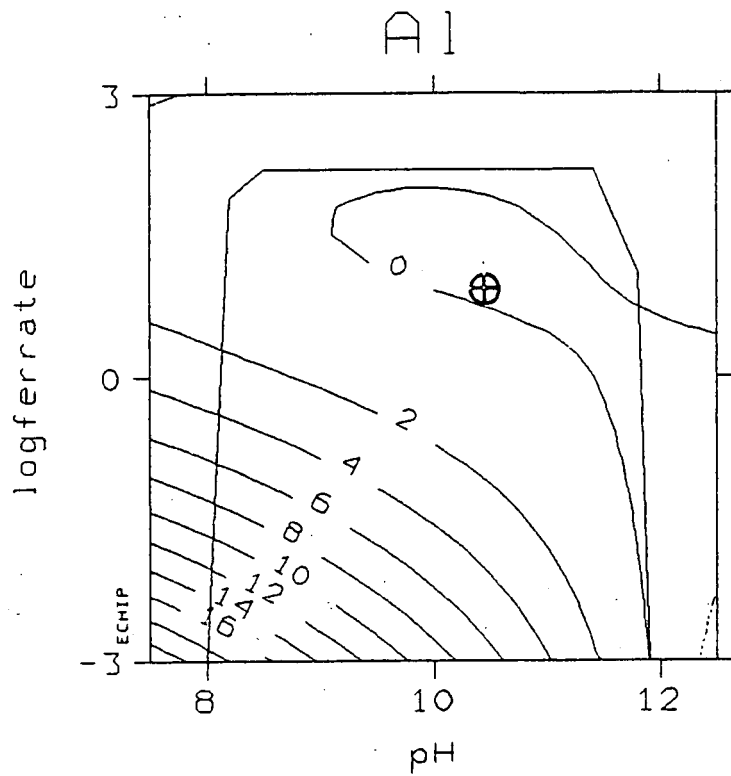
pH=10.35 log ferrate=1.20		
Value	Low Limit	High Limit
0.028	-0.090	0.146



EE-10 pH=10.35 log ferrate=-1.02			
Value	Low Limit	High Limit	
0.04	-0.48	0.56	



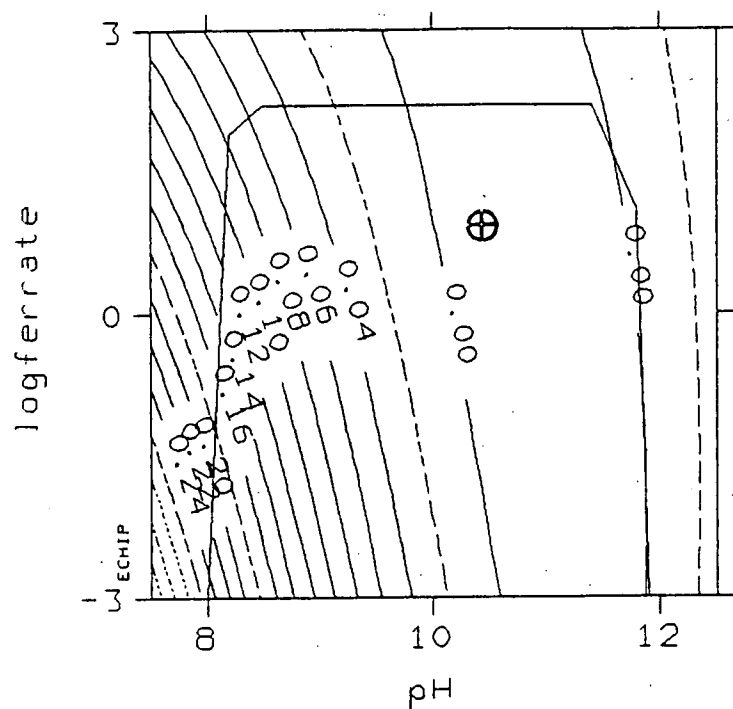
pH=10.35 log ferrate= 1.02		
Value	Low Limit	High Limit
0.0107	-0.0044	0.0258



pH=10.35 log ferrate=1.02			
Value	Low Limit	High Limit	
-0.09	-1.13	0.94	

Ba

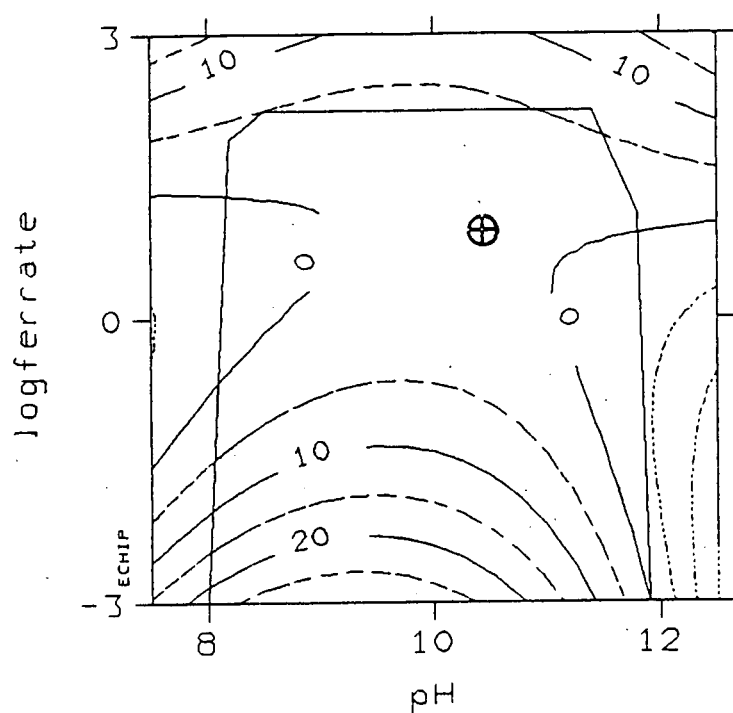
Lack of Fit



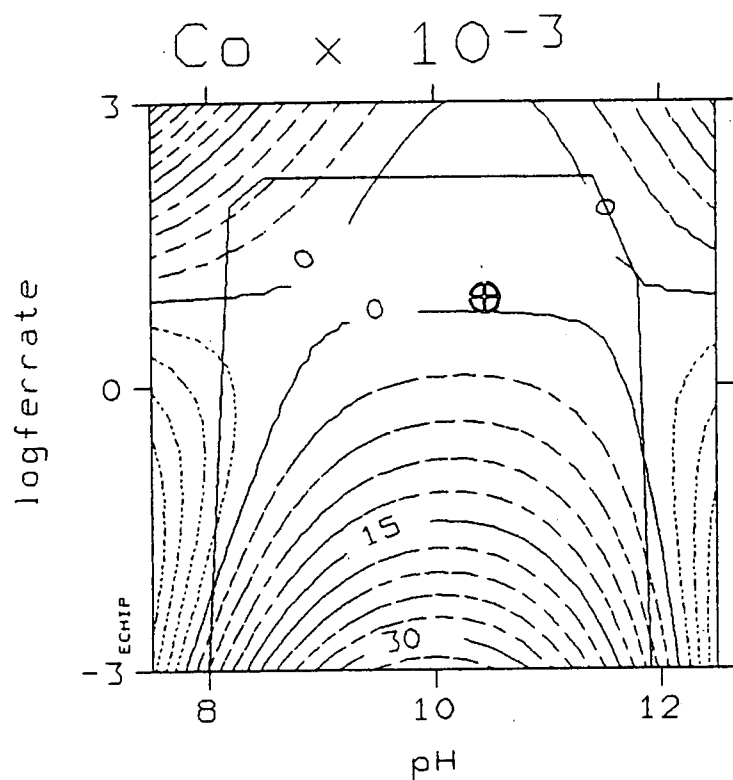
pH=10.35		logferrate= 1.02	
Value	Low Limit	High Limit	
-0.008	-0.035	0.020	

Cr $\times 10^{-3}$

Lack Of Fit

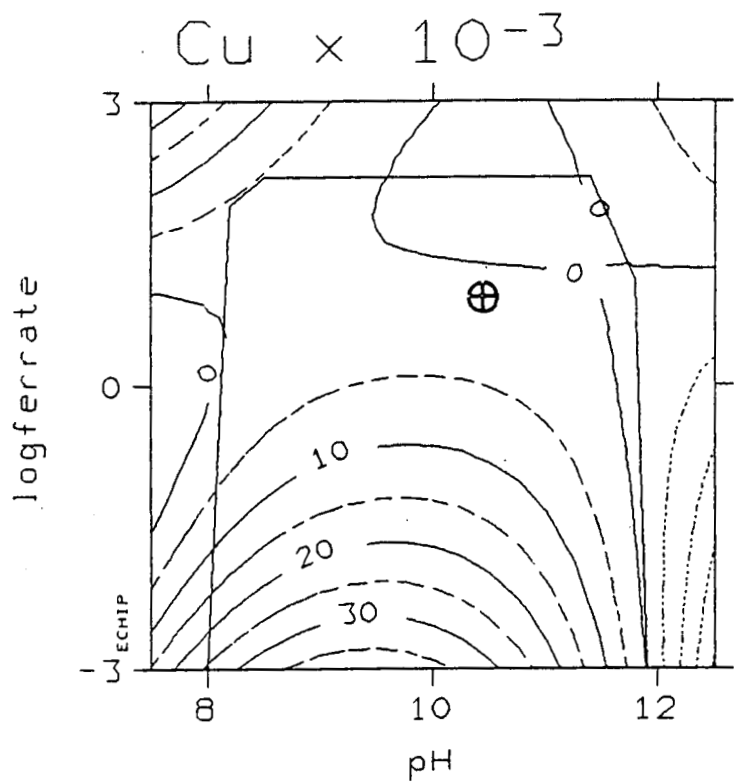


pH=10.35 log ferrate=1.02		
Value	Low Limit	High Limit
0.0007	-0.0078	0.0091



Lack Of Fit

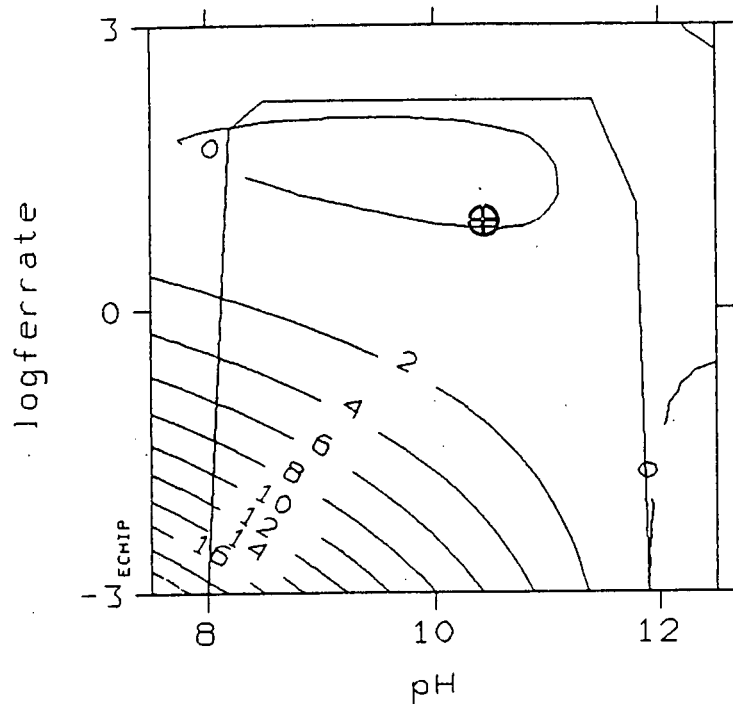
pH=10.35 logferra=1.02		
Value	Low Limit	High Limit
-0.0008	-0.0169	0.0153



pH=10.35		logferra= 1.02	
Value	Low Limit	High Limit	
0.0007	-0.0109	0.0124	

Fe

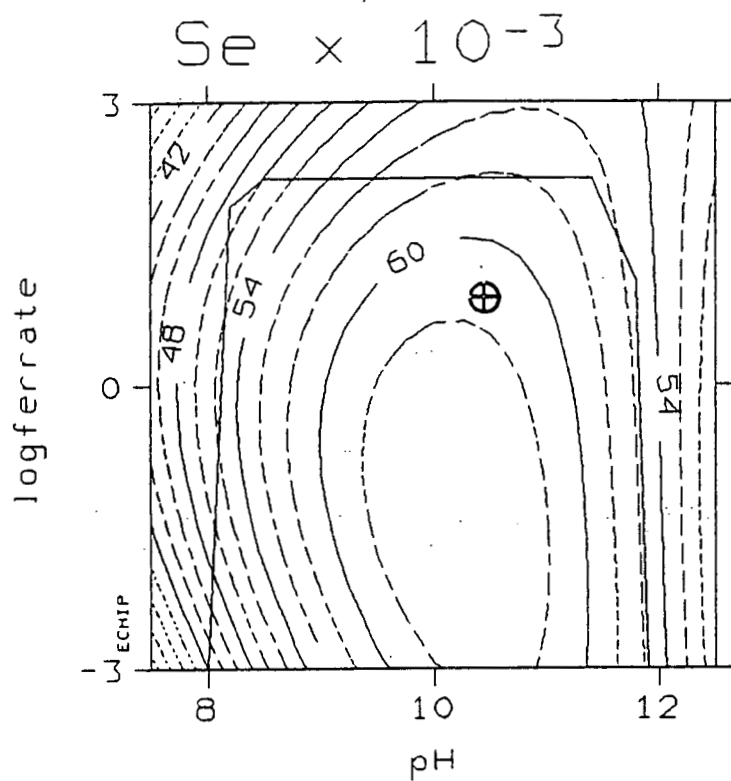
Lack Of Fit



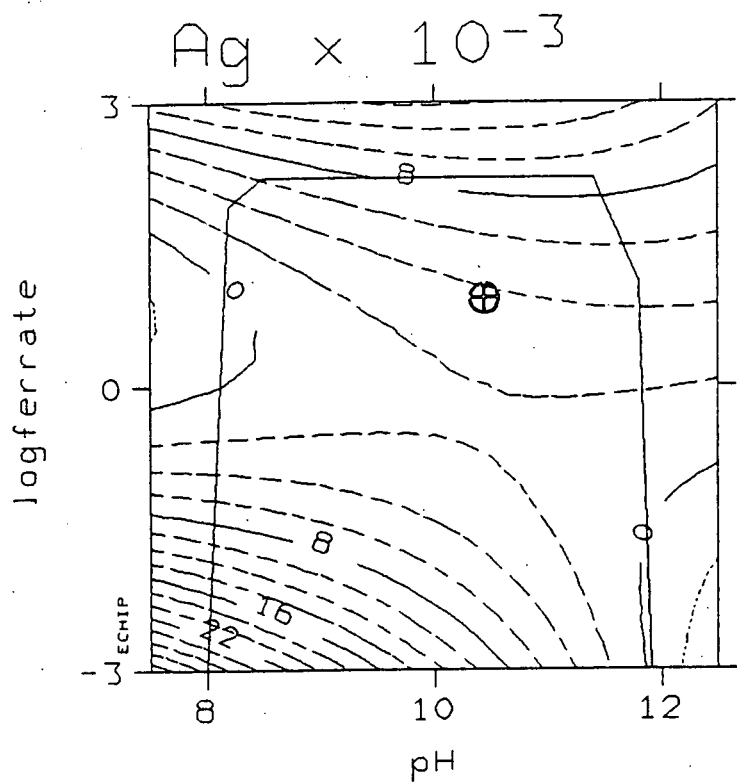
pH=10.35

1.02

	Low Limit	High Limit
-0.06	-0.32	0.21

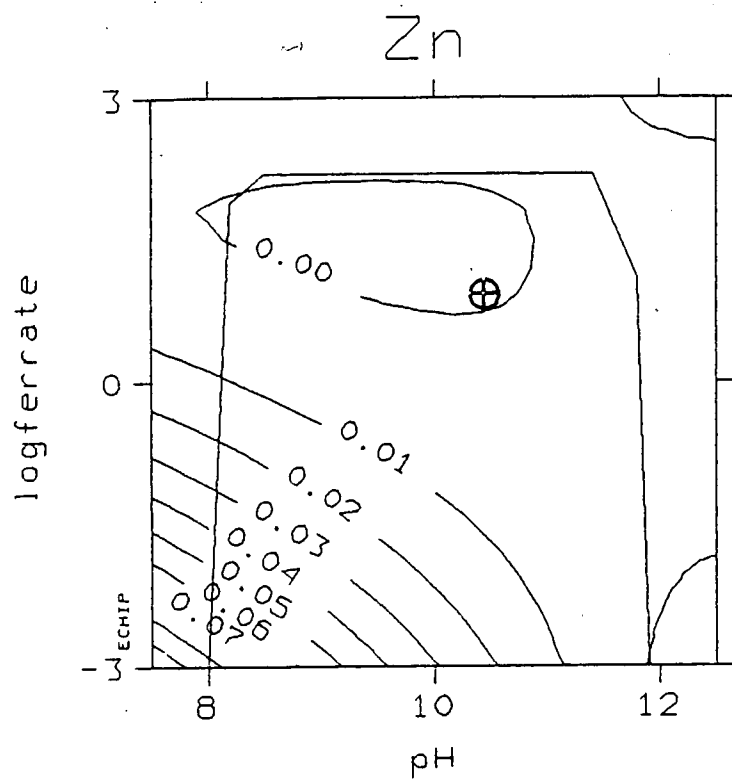


pH=10.35		log ferrate=1.02	
Value	Low Limit	High Limit	
0.0613	0.0539	0.0686	



Lack Of Fit

pH=10.35		logferra= 1.02	
Value	Low Limit	High Limit	
0.0038	-0.0044	0.0121	



pH=10.35		logferra= 1.02	
Value	Low Limit	High Limit	
-0.0004	-0.0043	0.0035	